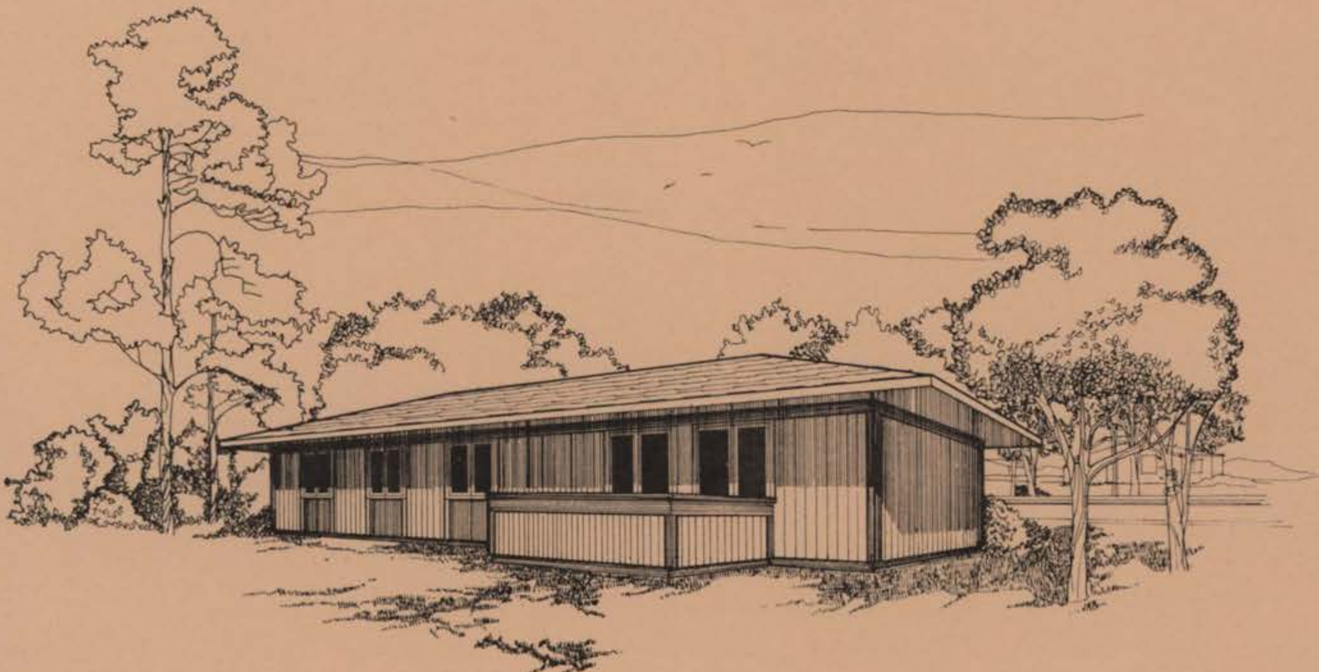
COMPUTER STUDIES OF PASSIVE-SOLAR DESIGN

Research Report 82-3



Small Homes Council-Building Research Council University of Illinois at Urbana-Champaign

SMALL HOMES COUNCIL-BUILDING RESEARCH COUNCIL

The Small Homes Council-Building Research Council was established by the University of Illinois as an agency for research, publication, education, and public service in the area of housing and building. Its program is keyed to take advantage of the many University resources — its laboratories and specialists — in the many subjects related to housing and building.

The Council conducts research independently or jointly with other departments, primarily under the sponsorship of governmental agencies, trade associations, and individual companies, such projects supplemented by those funded by the University and by the sale of publications. These projects have been primarily in the areas of construction and design.

Many of the Council's studies have been in the areas of simplifying construction methods and adapting large-scale building techniques to the needs of the small builder. Of particular importance has been the work in roof-truss construction and the wall-panel framing system. One of the major research concerns has been with how much space families need in their homes and how that space should be arranged. Special attention has been given to the design of kitchens, and to energy conservation and solar utilization.

Unless research findings reach the hands of people who can use them, research is of little value. For this reason, publications are an important part of the Council's program. A complete list of Council publications is available upon request to the Council at One East Saint Mary's Road, Champaign, IL 61820. This activity is a nonprofit but self-supporting one, which is necessary because a major proportion of the publications are distributed out of state.

In addition, the Council extends its information services to homeowners and industry by conducting a limited housing advisory service. Specific questions relating to planning and construction, not covered in SHC-BRC publications, are answered by staff members within the limitations of the demands of education and research on their time. The Council does not draw or review house plans for individuals. These inquiries preferably should be made by mail. Telephone inquiries should be restricted to morning hours, except in emergencies, to (217) 333-1801. Personal visits may be made to the Council offices at One East Saint Mary's Road, Champaign, Illinois. Appointments are preferred.

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CONTENTS

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Michael J. Siminovitch is a graduate student in the School of Architecture at the University of Illinois and is the holder of the Edward C. Ware and the Francis J. Plym Fellowships.

Computer Simulation Program

All computer simulations described in the following four separate articles used the same computer simulation program as described here.

B.L.A.S.T.

The program used in this study was the Building Loads And System Thermodynamics (BLAST) program. BLAST consists of a comprehensive set of subprograms for simulating building and system performance. Three major subprograms make up BLAST: (1) space load, (2) air distribution systems, and (3) central-plant simulation. The space-loads predicting subprogram was used independently in this study because the Btu prediction given by the space-loads subprogram is an adequate indication of the predicted performance of each option. BLAST performs hourly room heat balance calculations for the period simulated using a weather tape for user-specified weather conditions. The loads subprogram performs a complete radiant, convective, and conductive heat balance hourly for each surface of each zone simulated, and an hourly heat balance on the room air. Solar loads, infiltration loads, transmission loads, internal heat gains, and the temperature control strategy are included in the heat balance calculations. Of particular importance in the simulation of a passive-solar building is the method by which a predictive program handles solar input and building mass. The BLAST program calculates the following parameters important to passive simulations:

a. the shaded and sunlit areas of all exterior surfaces, considering specified attached and detached shadow-casting surfaces.
b. the effects of inside solar and infrared absorptivities are calculated.
c. the solar flux transmitted through single- or multiple-glazed windows is calculated using basic optical principles.
d. the calculation of response factors and conduction transfer functions for all zone surfaces provides consideration of transient heat conduction through walls and heat storage in room materials (mass).

Weather Tapes

The simulations were conducted using TRY weather tapes. The Test Reference Year tapes are produced using data from the National Climatic Center of the National Oceanic and Atmospheric Agency (NOAA). The BLAST procedure has created solar data using cloud cover data from the surface data tapes and approximative functions. Test Reference Year tapes used in this study contain hourly weather information for Indianapolis in 1972 and Albuquerque in 1959.

Optimum Window Sizing for a Super-Insulated House

Michael T. McCulley
Michael J. Siminovitch

This paper was published in the Proceedings of the 4th National Passive Solar Conference, October 3-5, 1979, sponsored by the American Section of the International Solar Energy Society.

ABSTRACT

Determining the optimum area of southern facing glass for super-insulated, passive solar homes is an area of immediate concern for people in less than optimum solar heating areas, such as the Midwest. In this study, the performance of a residence of varying window area, mass, and insulation as simulated using BLAST, a large hourly thermal simulation program with passive solar load capabilities. Weather tapes were employed in this study to provide annual energy use information for various options.

INTRODUCTION

The intention of this research is to use a computer-based thermal modeling program in developing standards for a specific type of passive solar design in a given locale. Various approaches to light-frame, super-insulated residential construction are simulated with incrementally increasing areas of direct-gain south glazing. A one-year simulation was conducted for each building option using a weather tape containing detailed hourly climatological data. The weather tape chosen for the Midwestern study was Indianapolis, Indiana. Indianapolis was chosen because its annual weather patterns are comparable to a broad band of the central Midwest. Certain studies were duplicated employing a weather tape for Albuquerque, New Mexico, in order to observe the effects of very different climatic conditions with a great deal of winter sun upon the results of the design variations.

The goal of this study was to determine the optimum amount of south glazing for each building variation, and to plot the effects of each variation upon annual heating and cooling loads. The tendency for each option to overheat was also plotted. Full-year simulations, calculated hourly, were conducted for each glazing area variation of each building type. The result of each simulation was plotted. Optimization curves were developed illustrating graphically the predicted effects of varying south glazing in each location.

TABLE 1. ZONE SURFACES

Zone Surface	Area sq. ft.	U-value Btuh/sq.ft./°F	Mass lbs./sq. ft.	Total Mass lbs.	Orientation Direction
Ceiling Under Attic	1568	.026	1.87	2,932	Up
Exterior Wall (30″ overhang)	448*	.035	3.75	1,680	South
* minus window					
Window	variable	.529	0	0	South
Exterior Wall	385.5	.035	3.75	1,445	North
Window	22	.529	0	0	North
Door	20.3	.096	5.38	109	North
Door	20.3	.096	5.38	109	North
Exterior Wall	224	.035	3.75	840	East
Exterior Wall	224	.035	3.75	840	West
Partitions	2016	.67	3.75	7,560	N/A
Floor Over Crawl Space	1568	.05	2.125	3,332	Up
Optional 4″ Concrete Slab Floor	1568	.045	112.20	175,930	Up

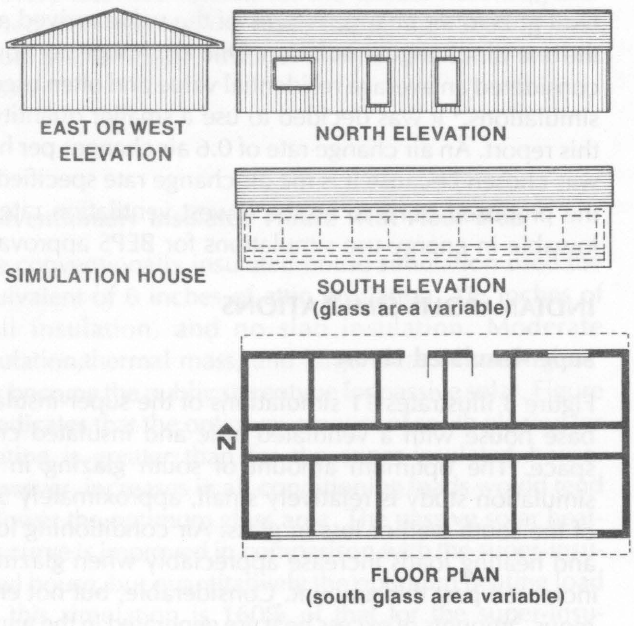


Figure 1. Elevations

TEST MODEL BASE HOUSE

Conditioned Space

Total area of this house is 1,568 sq. ft. (28′ x 56′) with its long axis oriented east-west. All surfaces of the conditioned space are listed in Table 1. These material specifications represent the thermal characteristics of standard construction materials.

TABLE 2

Percent of South Wall in Glass	South Glazing sq. ft.	Percent of Gross Floor Area in South Glass
10	44	2.8
20	88	5.6
30	132	8.4
40	176	11.0
50	220	14.0
60	264	16.8
70	308	19.6
80	352	22.4
90	396	28.0
100	440	28.0

Floor Options

Simulations were done of both crawl-space and slab-on-grade options. In the crawl-space option, the crawl-space floor and walls have a U-value of 0.05. In the slab-on-grade simulation, a heavy floor slab is specified, adding 172,000 pounds to the mass of the conditioned space. Insulation is installed beneath the slab so that it has approximately the same U-value as the floor over the crawl space. Thermal mass was considered for all materials.

Ventilated Attic

The house has a ventilated attic with a 70 cfm base air change rate, varying with wind velocity. The gable roof surfaces (1904 sq. ft.) face north and south at 19° or 4-12 pitch . The gable ends face east and west. Heat transfer between the conditioned space and the attic is included in load calculations.

SIMULATION PROCEDURE

Internal Loads

The internal load chosen for this simulation was 10kWh or 51,000 Btu per day. Corresponding to a user survey conducted at Princeton,[2] 25% of the load was scheduled continuously to simulate constant loads such as refrigerators and water heaters. The remaining 75% of the internal loads were scheduled to correspond to residential occupancy patterns. The house was simulated with three people at varying occupancy levels through the day and week.

Control Profile

All of the model houses were simulated using a 'deadband' control profile. The term deadband merely refers to the temperature range in which a mechanical system is not heating or cooling. Except where noted, all of the simulations in this study were operated in a 70°-78°F deadband. If the temperature of the interior, considering the overall heat balance, was calculated to drop below 70°, the amount of heat required to maintain a balance at 70° was recorded for each hour simulated. At the other end of the deadband, the amount of cooling required to maintain the heat balance below 78°, when calculated loads were excessive, was also recorded. If the heat balance resulted in interior air temperatures between the designated heat and cool points, no loads were indicated. A 70°-78° deadband was chosen for this study for two major reasons: 1) This range is a conventionally accepted comfort range. 2) BEPS has tentatively chosen this range for performance prediction simulations.

In these simulations, the maximum specified temperature was maintained during periods of overheating in the winter. Air conditioning loads required to maintain this temperature were indicated. This mode of simulation can tell the building designer a great deal about wintertime overheating in quantitative terms.

Infiltration

The infiltration-ventilation rate has the greatest single impact on building energy performance (Figure 2). It is also the most difficult parameter to predict or model. The BLAST program has the capability to simulate the effects of varying wind speed upon infiltration rates. The base rate is specified, and the infiltration becomes a function of the base rate and the recorded wind velocity. This capability was not used in this study because of the lack of information concerning base rates and the overshadowing effect that predominant infiltration loads can have on other variables.

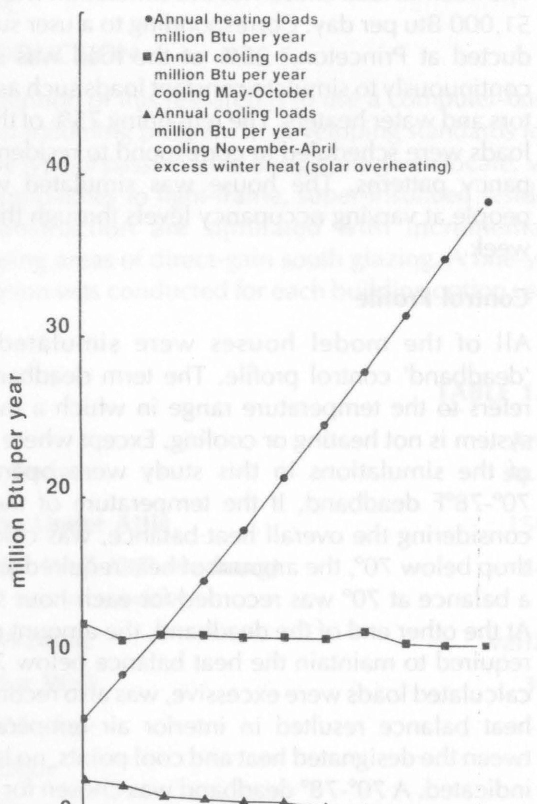
Infiltration Study

The effects of various constant infiltration rates upon the model were simulated. Constant infiltration rates, increasing from zero to one air change per hour in increments of one-tenth of an air change per hour, are illustrated in Figure 2. The predominant effect of infiltration on energy use can be seen in this example, where the model load at zero air change is 17% of the value arrived at in the one-air-change simulation. One air change per hour is considered an average residential value and often used in simulations.[4] It was decided to use a smaller quantity in this report. An air change rate of 0.6 air changes per hour was chosen because it is the air change rate specified by the proposed BEPS to be the lowest ventilation rate allowable in energy-use simulations for BEPS approval.

INDIANAPOLIS SIMULATIONS

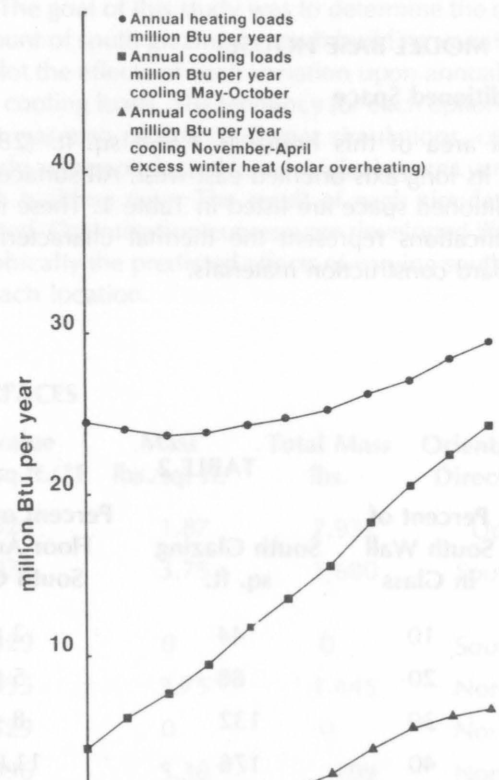
Super-Insulated House

Figure 3 illustrates 11 simulations of the super-insulated base house with a ventilated attic and insulated crawl space. The optimum amount of south glazing in this simulation study is relatively small, approximately 30% of the south wall or less in glass. Air conditioning loads and heating loads increase appreciably when glazing is increased past this amount. Considerable, but not enormous, amounts of excess heat are generated in the winter. For example, at 80% of the south wall in glass, if a 50%



INDIANAPOLIS – YEAR
infiltration load study
super-insulated
30% south glass model

Figure 2



INDIANAPOLIS – YEAR
super-insulated

Figure 3

recovery rate was figured for the excess heat and subtracted from the heating load, the annual heating load would still be higher than at 30% of the south wall in glass.

Conventionally Insulated House with Floor Slab

The conventionally insulated house simulation used the equivalent of 6 inches of attic insulation, 3½ inches of wall insulation, and no slab insulation. Moderate insulation,thermal mass, and large areas of south glass has become the public stereotype for passive solar. Figure 4 indicates that the optimum amount of south glazing for heating is greater than for the super-insulated house. However, increases in air conditioning loads would tend to lower the optimum glass area. The passive solar heating curve is improved in comparison with the super-insulated house, but quantitatively the optimum heating load for this simulation is 160% of that for the super-insulated example.

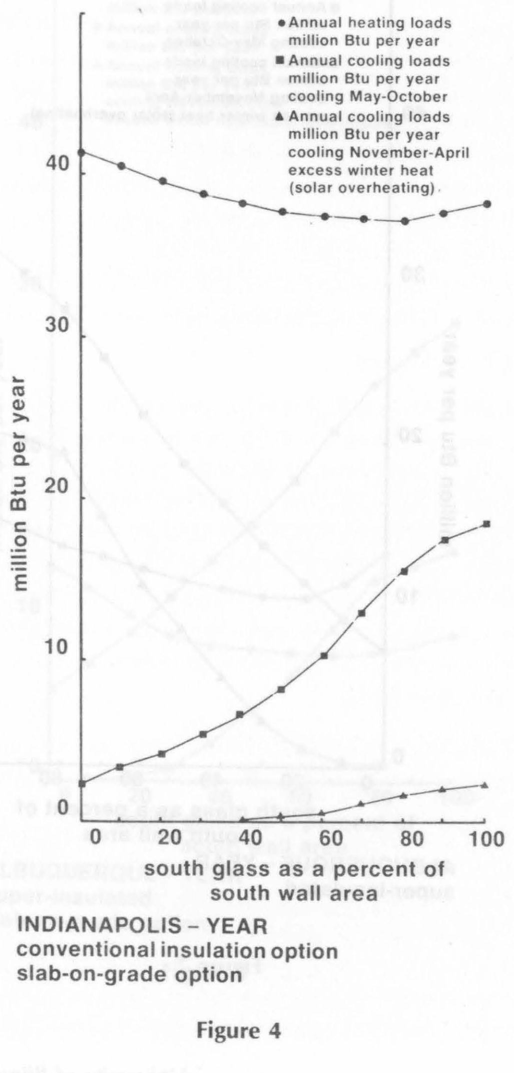


Figure 4

Super-Insulated House with Floor Slab

Figure 5 illustrates the results of simulations of a super-insulated structure with increased internal mass. The area of optimum south glazing is increased and the optimization curve is more pronounced than that of the super-insulated structure with a crawl space. Overall performance is very close to the house with a crawl space in both heating and cooling at the optimum glazing point.

Super-Insulated House with 65°—80° Deadband

A common statement associated with passive solar architecture is that wider temperature ranges must be tolerated in order to achieve the greatest performance from large areas of south glass. A wider temperature range was simulated in order to determine any change in the optimization curve. Figure 6 illustrates the great impact of a small change in the building control profile upon energy use. The predicted energy use quantities are markedly decreased in comparison, but the optimum glazing point has not been appreciably shifted, remaining at about 30% of the south wall in glass.

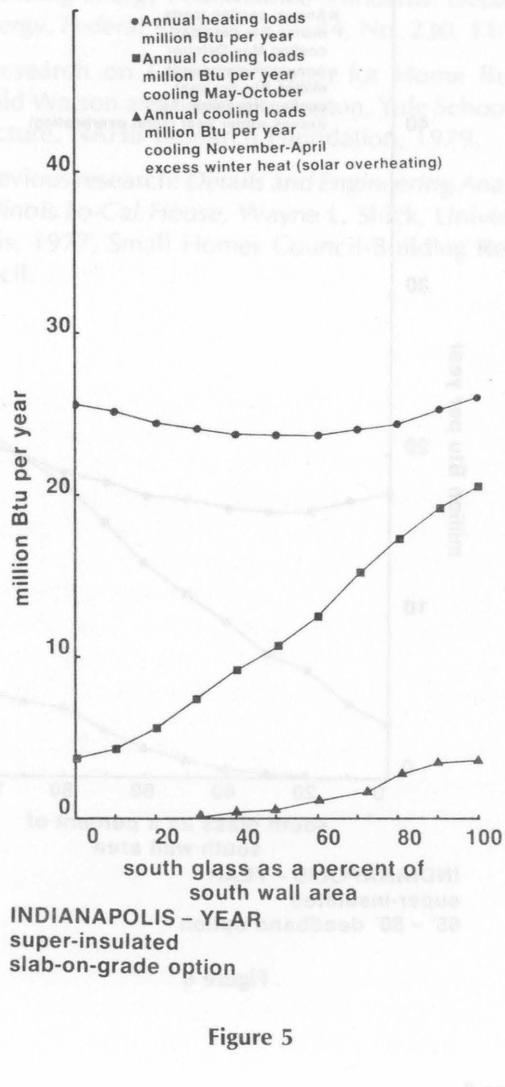


Figure 5

ALBUQUERQUE SIMULATIONS

Super-Insulated House - Albuquerque Comparison

Figure 7 illustrates a simulation series for the light-frame super-insulated base house using an Albuquerque, New Mexico, weather tape. A comparison with the base house Indianapolis simulation shows that predicted optimum south glass area in Albuquerque is very close to that of Indianapolis. The winter cooling curves indicates that more temperature damping and heat-storing mass could be beneficial in Albuquerque.

Super-Insulated House with Slab – Albuquerque Comparison

This is a series of simulations of a super-insulated slab-on-grade building using an Albuquerque weather tape. Comparing the plot of those simulations (Figure 8) with those of lighter construction (Figure 7) indicates that more mass in Albuquerque helps both the air conditioning and heating curves. The optimum glazing point is greater and loads are decreased at any specific glazing area. Mass tends to be much more beneficial in simulations of this climate than Midwestern simulations.

SUMMARY

Computer-simulated energy-use prediction programs have received increasing attention by architects and building designers as conventional energy sources become more precious. The proposed national Building Energy Performance Standards (BEPS) places great emphasis on computer modeling of predicted building performance. Direct-gain passive solar energy can be a powerful approach to decreasing the space-conditioning energy used by a structure.

As progress is made in the energy-efficient design of the buildings, it is becoming increasingly evident that a structure must be planned with the specific climate as a major factor. This is especially true when designing a building to receive passive direct solar gain. Comparison of the Albuquerque simulations with the Indianapolis simulations reveals very different relationships between optimum south glass areas and excess winter heat to the building designer. This demonstrates the need for simulation studies to be conducted for a specific climate type in order to accurately estimate the effects of solar strategies on long-term energy use.

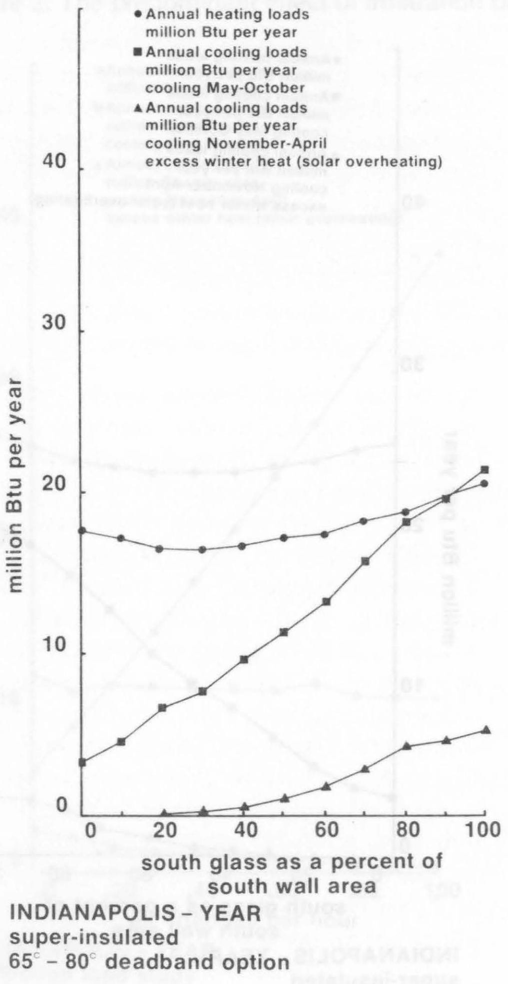


Figure 6

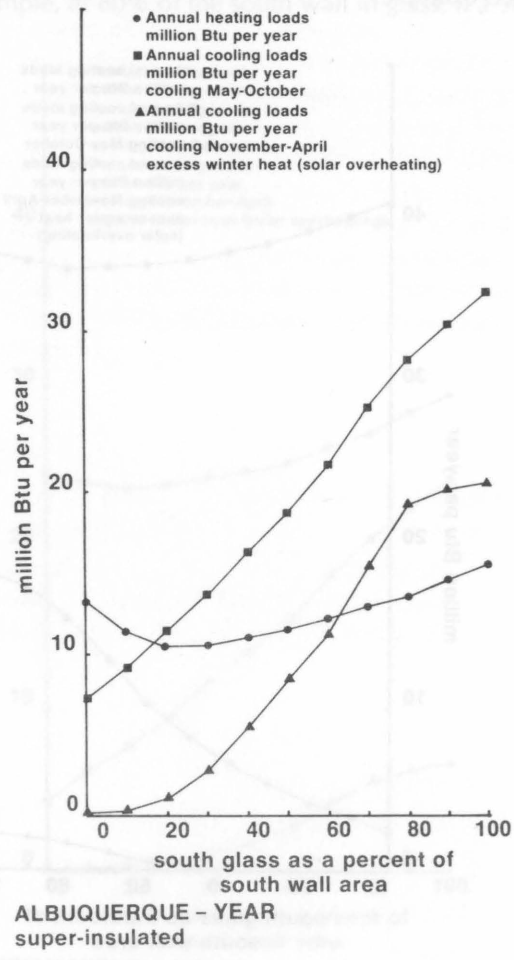


Figure 7

The graphic curves produced would be valuable tool for an individual designing a similar or comparable structure in similar climatic conditions. Analysis of simulation results for a specific situation can lead the designer to develop and simulate more efficient approaches to solar energy problems. Excessive heat loss from glazing during off solar hours in the Midwest leads to ways of reducing those losses. We have found that approaching such as variable thermal barriers, in turn, can be tested initially by simulation techniques to predict relative benefits.

FURTHER RESEARCH

The Small Homes Council-Building Research Council intends to instrument two adjacent super-insulated passive-solar houses. Results of collected data will be compared with simulated predicted performance for those structures in various modes.[5] Work will be concerned with such subjects as thermal shutters, optimum infiltration-ventilation techniques, and heat flow through wall insulation.

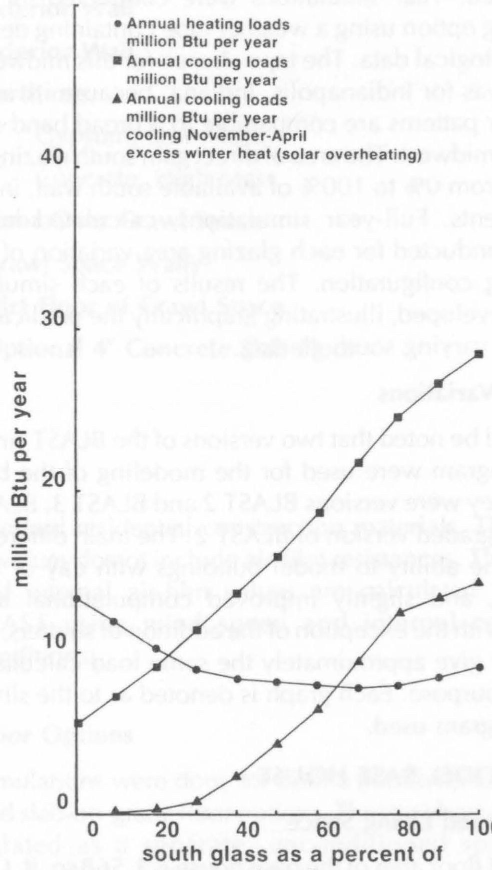


Figure 8

ACKNOWLEDGEMENTS

(1) This study has been made possible by assistance of computer time and financial assistance from the Research Board-Graduate College, University of Illinois.

(2) Assistance in computer simulation was given by C. O. Pederson, Mechanical Engineering Department, University of Illinois.

(3) This paper was developed in cooperation with Michael J. Siminovitch.

REFERENCES

(1) BLAST was developed as a user-interfaced, second-generation version of the National Bureau of Standards NBS/LD program. The principal investigator was Douglas Hittle. Building Loads Analysis and Systems Thermodynamics (BLAST) U.S. Army Construction Engineering Research Laboratory (CERL), June 1979.

(2) *The Twin Rivers Program on Energy Conservation in Housing*. Robert H. Socolaw, Princeton University, *Energy and Buildings*, April 1978.

(3) Building Energy Performance Standards. Department of Energy. *Federal Register*, Vol. 44, No. 230, 11/28/79.

(4) Research on Climate Design for Home Builders. Donald Watson and Keith Harrington, Yale School of Architecture, NAHB Research Foundation, 1979.

(5) Previous research: *Details and Engineering Analysis of the Illinois Lo-Cal House*, Wayne L. Shick, University of Illinois, 1977, Small Homes Council-Building Research Council.

Optimizing South Window Areas for Variations in Insulation, Mass, and Use of Insulating Shutters

Michael T. McCulley
Robert J. O'Meara
Michael J. Siminovitch

This paper was first presented at the 4th Miami International Conference on Alternative Energy Sources held on December 14-16, 1981, at Miami Beach, Florida, under the sponsorship of the Clean Energy Research Institute, University of Miami, in cooperation with the International Association for Hydrogen Energy.

ABSTRACT

The intention of this research is to investigate the capabilities of a computer-based thermal modeling program in developing window sizing standards for a super-insulated passive solar building in the midwest. In this study, the performance of the Illinois Lo-Cal House concept was simulated with varying window areas using the Building Loads And System Thermodynamics (BLAST) computer program and TRY weather data (1972) for Indianapolis, Indiana. Varying internal mass, moveable window insulation, and window sizes were modeled in two locations to find their effects and determine optimum window sizing. The goal of this study is to predict the optimum amount of south glazing for each building configuration. Plots of the effects of varying south glazing upon annual heating and cooling loads are given. The tendency for winter overheat is also plotted for each construction option. Summation of heating and cooling are investigated. This paper is a part of ongoing work in energy conservation for climates with cold, cloudy winters and hot, humid summers.

INTRODUCTION

For the past 36 years, since publications on solar homes in 1945, the Small Homes Council-Building Research Council at the University of Illinois has been interested in the development of energy-efficient buildings. In 1976, the Council published a circular about its work on an approach to the construction of energy-conserving light-frame structures. The basic approach, exemplified in the design of the Illinois Lo-Cal House, includes: maximum insulation; multiple glazing; and passive solar orientation. In the fall of 1979, the Council issued Technical Note 14, "Details and Engineering Analysis of the Illinois Lo-Cal House"[1]. This publication detailed the basis for the decisions made in the development of the Lo-Cal concept. Computer simulations of the concept house were made to determine thermal loads and energy requirements of the building using climate information from Madison, Wisconsin, and Indianapolis, Indiana. The Building Loads And System Thermodynamics (BLAST) program, developed by the U.S. Army Construction Engineering Research Laboratory, was employed to conduct the initial performance studies.

The publications concerning the development of the Illinois Lo-Cal super-insulated house concept have created interest relating to the optimum area of south glazing to be used in a super-insulated building. Determining the optimum configuration and area of south-facing glass for super-insulated passive-solar homes is an important design consideration in areas with less than the optimum winter conditions for solar heating, and hot, humid summers, such as the Midwest. Various approaches to light-frame super-insulated residential construction were simulated. Year simulations were conducted for each building option using a weather tape containing detailed climatological data. The tape chosen for this midwestern study was for Indianapolis, Indiana, because its annual weather patterns are comparable to a broad band of the central midwest. The area of direct gain south glazing was varied from 0% to 100% of available south wall, in 20% increments. Full-year simulations, calculated hourly, were conducted for each glazing area variation of each building configuration. The results of each simulation were developed, illustrating graphically the predicted effects of varying south glazing.

BLAST Variations

It should be noted that two versions of the BLAST simulation program were used for the modeling of the buildings. They were versions BLAST 2 and BLAST 3. BLAST 3 is an upgraded version of BLAST 2. The main differences are in the ability to model buildings with day or night shutters, and slightly improved computational algorithms. With the exception of the addition of shutters, both versions give approximately the same load calculations for our purpose. Each graph is denoted as to the simulation program used.

TEST MODEL BASE HOUSE

Conditioned Living Space

The total floor area of the base house is 1,568 sq. ft. (28 ft. x 56 ft.) with its main axis oriented east-west. This east-west orientation is the customary passive solar orientation used to take full advantage of direct solar gain in the winter and minimized gain in the summer. Surfaces for the conditioned space are listed in Table 1. These material specifications represent the thermal characteristics of

TABLE 1. ZONE SURFACES

Zone Surface	Area sq. ft.	U-value Btuh/sq.ft./°F	Mass lbs./sq. ft.	Total Mass lbs.	Orientation Direction
Attic Roof, South	952	.569	3.60	3,427	South
Attic Roof, North	952	.569	3.60	3,427	South
Attic End Wall, East	85.3	.324	2.14	182	East
Attic End Wall, West	85.3	.324	2.14	182	West
Ceiling Under Attic	1568	.025	1.87	2,932	Up
Exterior Wall (30″ overhang)	448*	.034	8.34	3,736	South
* minus window					
Window, 30″ overhang	variable	.365	0	0	South
Window w/Thermal Shutter	variable	.080	0	0	South
Exterior Wall (30″ overhang)	385.5	.034	8.34	3,210	North
Window	22	.365	0	0	North
Door	20.3	.089	5.34	108	North
Door	20.3	.089	5.34	108	North
Exterior Wall	224	.034	8.34	1,868	East
Exterior Wall	224	.034	8.34	1,868	West
Partitions					
Gypsum, Low Mass	1792	.350	3.74	6,702	N/A
Concrete, High Mass	1792	.439	50.40	90,317	N/A
Floor Over Crawl Space	1568	.047	2.125	3,332	Up
Crawl Space Walls	434	.046	158	68,572	N/A
Dirt Floor of Crawl Space	1568	.094	65	101,920	Up
Optional 4″ Concrete Slab Floor	1568	.044	112.20	175,930	Up

standard residential construction materials. The surface U-values do not include air-film resistances. The external and internal air-film values are calculated hourly by BLAST using wind speed and internal convection conditions.

Floor Options

Simulations were done for both a floor over crawl space and slab-on-grade floor options. The crawl space was calculated as a separate, unconditioned space. Heat transfer through the floor between the crawl space and the conditioned living space can then be calculated. No air exchange or infiltration was simulated between the conditioned space and the crawl space. In the crawl-space option, the floor and crawl-space walls have a U-value 0.047 Btu/sq. ft./°F. The mass of the ground is considered in the calculations. For the slab-on-grade simulation, a heavyweight concrete floor slab was specified, adding 175,930 lbs. to the internal mass of the conditioned space. The concrete walls used in the simulation added an additional 90,317 lbs. The floor slab was insulated below with two inches of polystyrene and had approximately the same U-value as the floor over the crawl space. The thermal mass of all materials was considered.

Ventilated Attic

The base house had a ventilated attic with a 70 cfm base air change rate—about .33 air changes per hour at 7.5 mph—varying with the wind velocity. The gable roof surfaces (952 sq. ft. each) face north and south at 19° pitch (4/12). The gable ends face east and west with an area of 85 sq. ft. each. The attic was simulated as a separate zone. The hourly attic temperatures were calculated and heat transfer between the conditioned living space and the attic were included in the load calculations.

SIMULATION PROCEDURE

Internal Loads

The base internal load chosen for this simulation was 15 kWh (51,000 Btu) per day. Corresponding to a user survey conducted at Princeton[3], 25% of this base load was scheduled continuously to simulate constant loads such as refrigerators, water heaters, etc. The remaining 75% was scheduled to correspond to a residential occupancy schedule. The residential schedule used had full occupancy during the evening and night hours but only one occupant present during the day for Mondays through Fridays. The weekends were slightly modified to account for being out of the house in the evening. We considered this occupancy schedule to be indicative of an average household with three occupants.

Temperature Control Profile

All of the various model houses were simulated using a "deadband" temperature control profile. A "deadband" control refers to having a specified temperature range in which the mechanical system is not heating or cooling the living area. Except where noted, all of the simulations in this study were conducted with a 70°F-78°F deadband setting. If the temperature of the interior space, considering the overall heat balance, was calculated to drop below 70°F, the amount of heat required to maintain a balance of 70°F was recorded for each hour simulated. At the other end of the deadband, the amount of cooling required to maintain the heat balance below 78°F, when calculated loads were excessive, was also recorded. If the heat balance resulted in interior air temperatures between the designated heating and cooling points, no loads were indicated. A 70°F-78°F deadband was chosen for this study for two reasons: 1) This is the conventionally accepted comfort range, 2) BEPS[4] tentatively chose this range for performance prediction simulation.

In these simulations, the maximum specified temperature was maintained in the winter by air conditioning when necessary. Air conditioning loads required to maintain this temperature were indicated. The data generated from this type of simulation can tell the building designer a great deal about winter overheating in quantitative terms.

Infiltration Studies

Of all the individual factors influencing the energy balance of a super-insulated building, the infiltration-ventilation rate has the greatest single impact on energy performance. At the same time, it is the most difficult parameter to predict and model. The BLAST program used does have the capability to simulate the effects of wind speed upon infiltration but it was decided not to use it. This variable infiltration rate is accomplished by specifying a base rate and the recorded wind velocity. Variable infiltration as a function of wind speed was not used in this study because of the lack of information concerning base rates and the overshadowing effect that predominant infiltration loads can have on the other variables. A constant infiltration rate was used in this study.

No special night-time summer cooling strategies were used, because of the high humidity conditions that are present through the day and night in much of the Midwest. In order to determine the infiltration rate to use, the effects of various constant infiltration rates on the base house were simulated. Constant infiltration rates, increasing from 0 to 1 air change per hour, in increments of two-tenths, were plotted in Figure 1. The predominant effect of infiltration on energy use can be seen in this example where the heating load for the model simulated at 0 air changes was 17% of the value arrived at for the 1-air-change simulation. The total energy load for the building—winter heating plus summer cooling—still showed a 38% difference from 0 to 1 air-change. In reducing the infiltration rate from 1 to 0.6 air-changes, the total energy decreased by 24%. This is strong evidence of the powerful effect of infiltration on building heating loads. An infiltration rate of 1 air-change per hour is considered an average residential value and is used often in simulations[5]. Because the model house was conceived as an energy-efficient house, with more emphasis

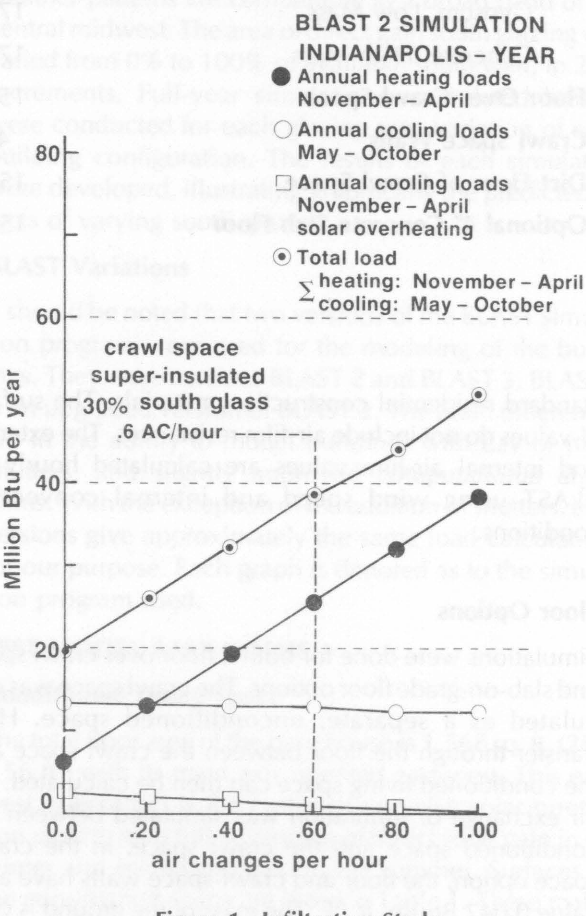


Figure 1. Infiltration Study

placed on controlling sources of energy loss, it was decided to use a smaller quantity in this report. An air-change rate of 0.6 air-changes per hour was chosen because it is the air-change rate specified by the proposed BEPS to be the lowest ventilation rate allowable in energy-use simulations for simulation approval. The rate of 0.6 air-changes per hour was constant in all simulations. Changes in infiltration rate had only a slight effect upon the building cooling loads.

OPTIMIZATION STUDIES

Building Simulations

From the various approaches to light-frame construction simulated, predicted performance plots were generated. Each variation of the model house was initially simulated with no south glazing. The south glazing was then incremented until the area was equivalent to 100% of the south wall. Note that with one exception there was no glazing on either the east or west ends of the house and the glazing on the north side of the building was constant at 2% of the floor area (31.3 sq. ft.). The annual heating load for each simulation, for the months of November through April, is indicated by a solid dot. The predicted air-conditioning load needed to maintain the internal temperatures within the specified deadband region during the heating season, winter overheat, is indicated on the charts by squares. The summer cooling loads for the periods of May to October are indicated by circles. The total energy load, winter heating and summer cooling, is indicated by a circle with a dot in it.

The magnitude of winter air conditioning is a quantitative measure of predicted daytime solar overheating. Large amounts of winter air-conditioning loads would indicate periods of excessive solar heating and the need for heat storage and temperature moderating measures such as increased internal mass. If small winter air-conditioning loads are predicted, this would indicate that increased internal mass would be of minimal benefit to energy performance. Two simulations for Albuquerque, New Mexico, have been included in this study in order to illustrate a contrasting relationship between winter heating and summer cooling. The infiltration rate was constant year-'round and no special night-time summer cooling strategies were used. The magnitude of cooling loads

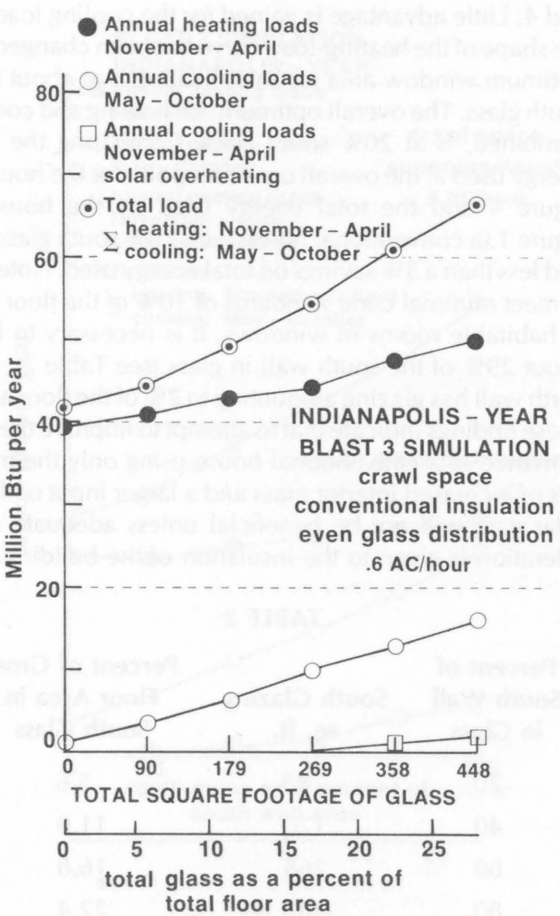


Figure 2. Conventionally Insulated House

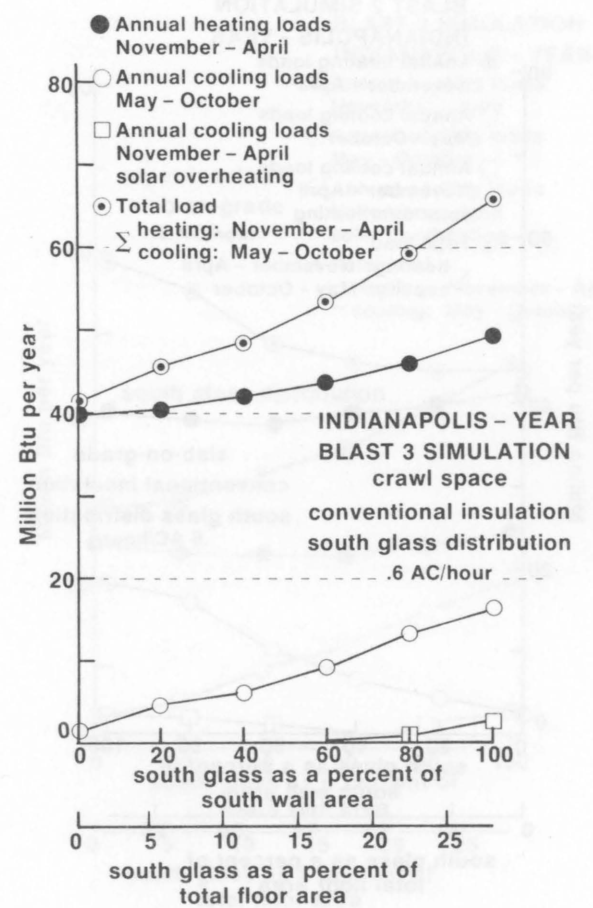


Figure 3. Conventionally Insulated House

could have been reduced with such approaches, but the relationship of the glass area to summer cooling requirements would have remained strong.

Conventionally Insulated House

This model house is a simulation of a relatively light structure. The internal mass is small, consisting primarily of the gypsum plaster on internal walls and partitions. This house embodies the basic construction techniques applied prior to our current energy-conscious designs. The walls have 3½ inches of insulation and the ceiling has 6 inches of insulation. These simulations show the predicted performance of the majority of homes today and will provide a scale to gauge the predicted performance of the other construction options.

Figures 2 and 3 are the plots of predicted performance for this type of building. In Figure 2, the window glazing is evenly distributed on all four walls. The total energy-load curve has an expected exponential form. As the window area is increased, the benefits of increased south glazing are overcome by the losses from the increased glazing areas on the north, east, and west sides of the house.

Figure 3 is the performance plot of the preceding building but with the glazing area being oriented to the south. This simulation was conducted with the north wall having the equivalent of 2% of the floor area as windows. There were no windows on either the east or west. It is interesting to note that southern window exposure adds little in the way of energy-load savings. Since little was gained from the increased southern exposure from otherwise identical simulation models, we conclude that insufficient insulation in the walls, floor, and ceiling has a much larger detrimental effect than can be overcome simply with southern window orientation. To make these simulations fair when compared to one another, 0.6 air-changes per hour infiltration rate was used for all simulations. It would be unlikely to find a house built prior to this energy-conscious era that could attain such a low infiltration rate. A higher infiltration rate would likely push the total energy load upward.

Figure 4 is a plot of the predicted performance of a conventionally insulated home, similar to that plotted in Figures 2 and 3 but with passive-solar techniques applied. The home has a 4-inch concrete slab and the glazing oriented to the south. The effect of this passive solar orientation and construction is to decrease the overall energy usage over that of a comparable house with a crawl space. When large amounts of south glass are employed, this is seen by comparing the data in Figures 3 and 4. Little advantage is gained for the cooling load but the shape of the heating-load curve has been changed. An optimum window area for solar heating is at about 60% south glass. The overall optimum, for heating and cooling combined, is at 20% south glass. Comparing the total energy used at the overall optimum point for the house in Figure 4 and the total energy used by the house in Figure 1 (a conventional house with 20% south glass) we find less than a 3% savings on total energy used. Note that to meet minimal code standards of 10% of the floor area of habitable rooms in windows, it is necessary to have about 29% of the south wall in glass (see Table 2). (The north wall has glazing amounting to 2% of the floor area.) These findings indicate that to attempt to improve the performance of a conventional house using only the methods of increased interior mass and a larger input of direct solar gain will not be beneficial unless adequate consideration is given to the insulation of the building.

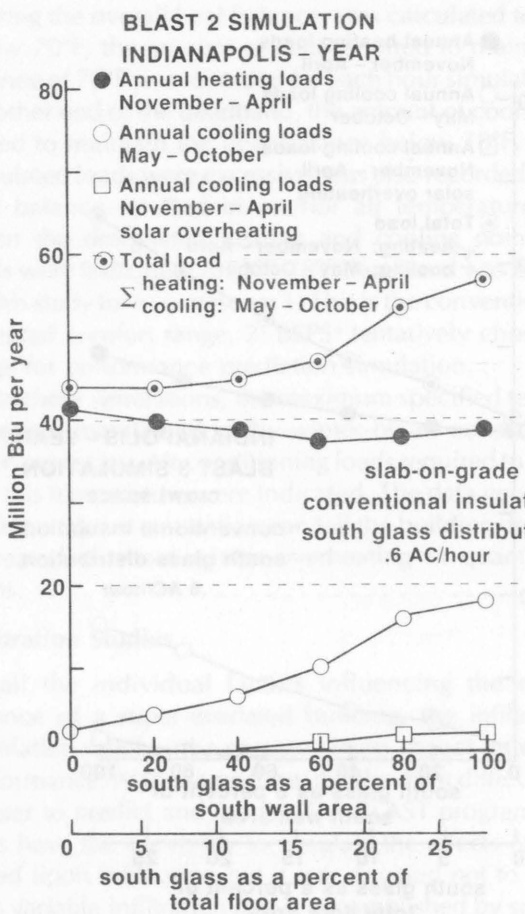


Figure 4. Conventionally Insulated House

TABLE 2

Percent of South Wall in Glass	South Glazing sq. ft.	Percent of Gross Floor Area in South Glass
20	88	5.6
40	176	11.0
60	264	16.8
80	352	22.4
100	440	28.0

Super-Insulated House

The need to adequately insulate houses, as previously discussed, prompted the Small Homes Council-Building Research Council to develop the Illinois Lo-Cal House. This model house is a simulation of a relatively light structure. The internal mass is relatively small, consisting primarily of the gypsum plaster on internal walls and partitions. The basis for this approach is the concept that a super-insulated house does not require a large mass for thermal storage or large amounts of southern glazing if the heat-loss rate is kept low. Figure 5 illustrates six simulations of the super-insulated base house with a ventilated attic and insulated crawl space. The optimum amount of south glazing, based on the heating-load curve, is at 20% south glass. This is below the minimum amount of window area needed to meet design codes. The air-conditioning and total-energy-load curves show no such optimum. Both curves show continual increases as window area is increased.

Some excess heat was generated in the winter. This would indicate some possibility of performance improvement by using additional heat-storage mass. Notice that for 29% south window area (minimum acceptable to meet code requirements) the total energy used for the super-insulated house with crawl space is 23% less than for the passive-solar home with only conventional insulation.

Super-Insulated House with Floor Slab

The shape of heating-load curve in the prior simulations and the reduction of winter overheating would tend to argue for a compromise or hybrid of the super-insulated and large-internal-mass approaches. One of the more logical ways to explore the benefits of increased mass in a super-insulated building would be to simulate a structure with heavily insulated walls built on a slab. This is because the floor is considered to be directly irradiated in the BLAST calculations.

Figure 6 illustrates the results of simulations of a super-insulated house with increased internal mass. The area of predicted optimum south glazing for the heating-load curve was increased to approximately 60% south window area. The heating optimization curve is more

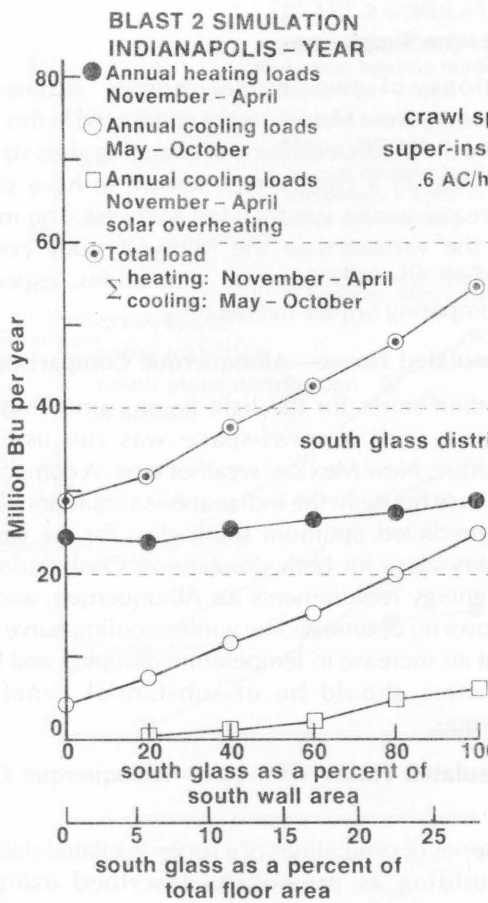


Figure 5. Super-Insulated House

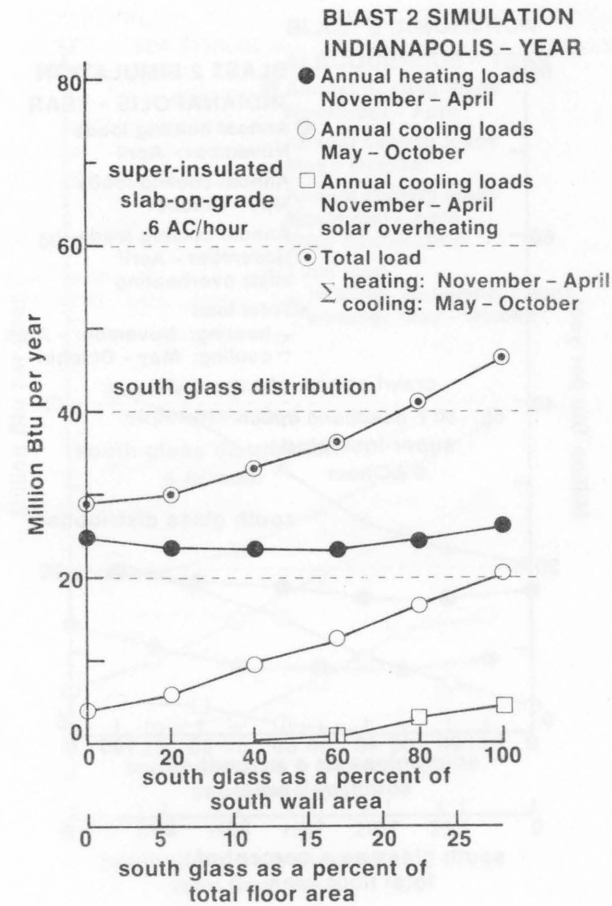


Figure 6. Super-Insulated House with Floor Slab

pronounced than that of a super-insulated structure with a crawl space. The introduction of the increased mass tends to bend all the curves downward, compared to the super-insulated, crawl-space simulation. There is, of course, negligible difference between both construction options when the window area approaches zero.

Comparison of this study with the prior simulations regarding winter heating loads and summer heating-cooling summations would tend to indicate that a greater increase in internal mass would not make significant improvements in the predicted performance of this model. Night-time and bad-weather losses, as well as air-conditioning load gains through the south glazing area, cancel out the benefits of increased solar input and thermal storage.

Super-Insulated House with 65° — 80°F Deadband

A common conception associated with passive-solar architecture is that wider temperature ranges must be tolerated in order to achieve the greatest performance from large areas of south glass. A wider temperature range was simulated in order to observe any change in the optimization curve. Figure 7 illustrates the great impact a small change in the building control profile has upon energy use. The predicted energy quantities are markedly decreased in comparison to Figure 5. The heating-load curve showed the largest overall reduction, about 34% decrease. The shape of the curves has not been appreciably changed and the optimum glazing point is almost the same.

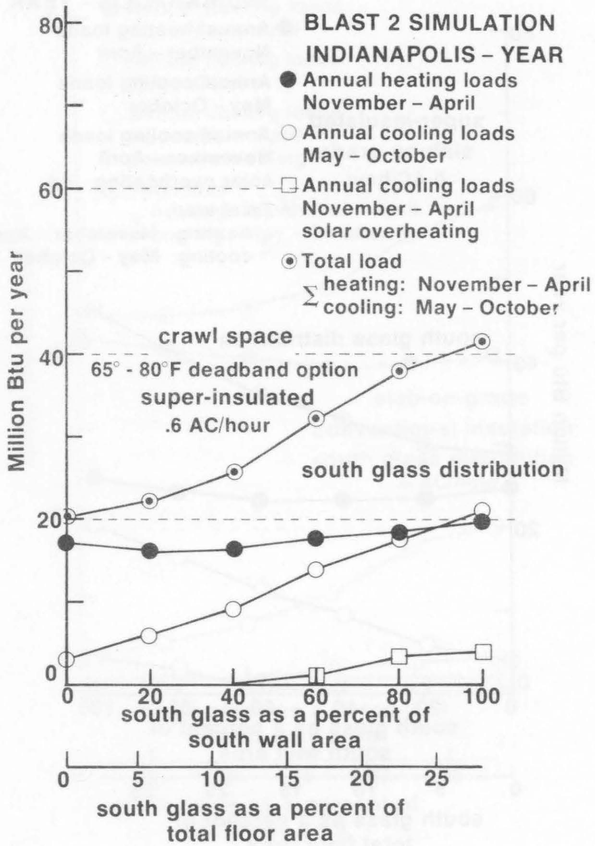


Figure 7. Super-Insulated House

The results of this simulation series appear significant in two ways. The first is the substantial decrease in predicted energy use resulting from the small change in the control profile. The best reduction as a result of solar gain without night insulation is less than 10% compared to an overall reduction of 32% with a small change in the control profile. These numbers are for 29% south glass, the percentage needed to meet minimum code standards, even though the optimum is closer to 20% south glazing based on the heating curve. The second important point is that, in the Midwest, these simulations indicate that widened temperature controls did tend to reduce predicted heating loads at all levels of glazing, but more glazing at wider temperature controls did not reduce the predicted heating loads.

CLIMATE COMPARISONS

Albuquerque Simulations

Simulations of two model homes situated in Albuquerque, New Mexico, were conducted in this study to observe the predicted effects of changing glass size and internal mass in a climate-type known to have significantly greater winter sun than the Midwest. The magnitude of the variations in the Midwest study contrast greatly with the Albuquerque simulations, especially when comparing winter overheating.

Super-Insulated House—Albuquerque Comparison

A simulation series for the light-frame, super-insulated base house with a crawl-space was run using an Albuquerque, New Mexico, weather tape. A comparison with the base house in the Indianapolis simulation shows that the predicted optimum south glass for the heating load is very close for both simulations. Cooling dominates the energy requirements for Albuquerque, and this curve shows no optimum. The winter-cooling curve indicates that an increase in temperature damping and heat-storage mass should be of substantial benefit in Albuquerque.

Super-Insulated House with Slab—Albuquerque Comparison

This is a series of simulations of a super-insulated slab-on-grade building as previously described using an Albuquerque weather tape. Comparing the plot of those simulations (Figure 9) with those of lighter construction

(Figure 8) indicates that, in contrast to Indianapolis, more mass in Albuquerque helps both the air-conditioning and heating-load curves. The optimum glazing point, based on the heating load, increased to about 80% south glass, and the total load is decreased for all glazing area possibilities.

The cooling load becomes the dominant factor as the optimum point on the heating-load curve is approached. The cooling and total-load curves still show no optimum glazing point. Assuming that the 29% south glass necessary to meet building codes is used, the total amount of energy saved by increasing the internal mass is 20% in Albuquerque. This compares with only a 3% savings on the conventional home and a 13% savings on the super-insulated house in Indianapolis. Mass tends to be much more beneficial in simulations of this climate than in Midwestern simulations. The contrast between Albuquerque and Indianapolis simulations is an example of how dependent on climate and location passive-solar architecture is.

REDUCTION OF HEAT-LOSS THROUGH GLAZING

Night Shutter Simulation

Night-time heat loss and cloudy weather are the major factors working against passive direct solar gain in the Midwest simulations. This simulation series was conducted to investigate the effects of night insulation on heating loads and optimum south-glazing areas. Earlier studies of the effect of night shutters on simulated loads in high-internal-mass buildings have shown a significant reduction in predicted heating loads and in optimum south glass areas.

These simulations were conducted on BLAST 3,[2] which has the capability to schedule the use of moveable insulation. The shutters had a U-value of 0.08. They were scheduled to be in place from sundown to sunup during the months of November through April (winter) and from sunup to sundown during May through September. The shutters were used only on the south window areas with triple-pane glass.

Night Shutters—Light-Frame, Super-Insulated

The results of night shutters scheduled for a light-frame, super-insulated house are plotted in Figure 10. The predicted heating load continues to be reduced as the glazing area is increased to 100% of the south-wall facade. The air-conditioning load curve shows an unexpected rise from 0 to 40% south-wall glazing, but declines from 40% on. Considering that 29% south glass is the minimum area allowed, the optimum for the cooling curve is

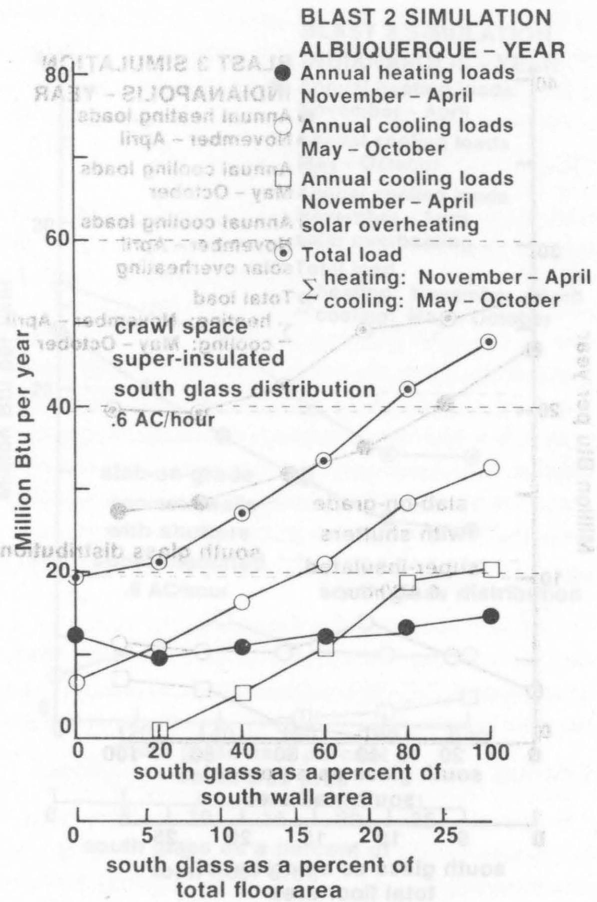


Figure 8. Super-Insulated House – Albuquerque

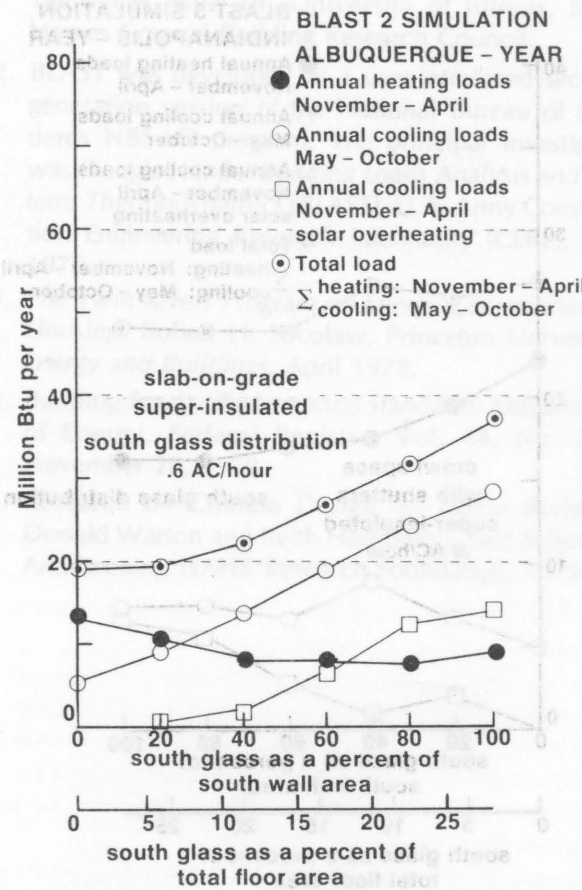


Figure 9. Super-Insulated House – Albuquerque

at 60% of the south facade in glass. The overall optimum appears to be between 60% and 80% of the south wall area being glass. The significant amount of winter overheating would indicate that increased internal mass would reduce the total energy load further.

Night Shutters—Super-Insulated Slab-on-Grade

Figure 11 illustrates the results of a series of simulations on the effect of night shutters on a super-insulated house built on a slab. A comparison of the results of this simulation series with Figure 10 finds the increased mass of the slab causing great changes in the shapes of all three optimization curves. For the heating-load curve, the increased mass of the slab initially causes an increased energy usage up to about 40% south glass. From 40% on, the increased mass appears to lower the heating load curve. The shape of the curve is very similar to that in Figure 10, an ever-decreasing curve. The cooling-load curve has the general shape of Figure 10 being shifted down about two million Btu per year. The optimum point on the cooling curve has been shifted from the previous 60% up to between 60% and 80%. The effects of the shifting of the heating- and cooling-load curves is to pivot the total-load curve down about the point of 0% south glass. This shifts the total optimum point past 80% of the south wall being glazed. The percentage drop caused by the added internal mass, at their respective optimum points, is about 29%. The reduction of the predicted total energy used at the respective optimum points with and without shutters is 35% with a crawl space and 39% with a concrete slab.

Since there is still an appreciable amount of winter over-heat, increased internal mass should be of some advantage.

Night Shutters—Super-Insulated Slab-on-Grade with Concrete Walls

Figure 12 illustrates the results from the simulations of the effects of extra internal mass and night shutters on a super-insulated slab-on-grade house. The increased mass has reduced winter overheat to an insignificant amount. It has also reduced the load curves from the previous series further. The total-load optimum point has been shifted all the way out to 100% of the south wall in glass. The percent reduction in predicted total energy use is an additional 15%.

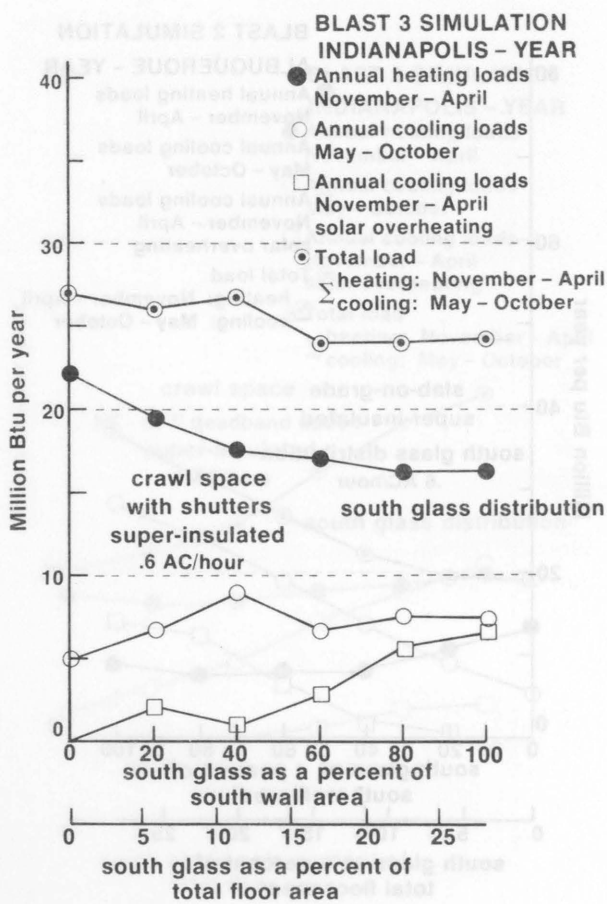


Figure 10. Super-Insulated House with Shutters

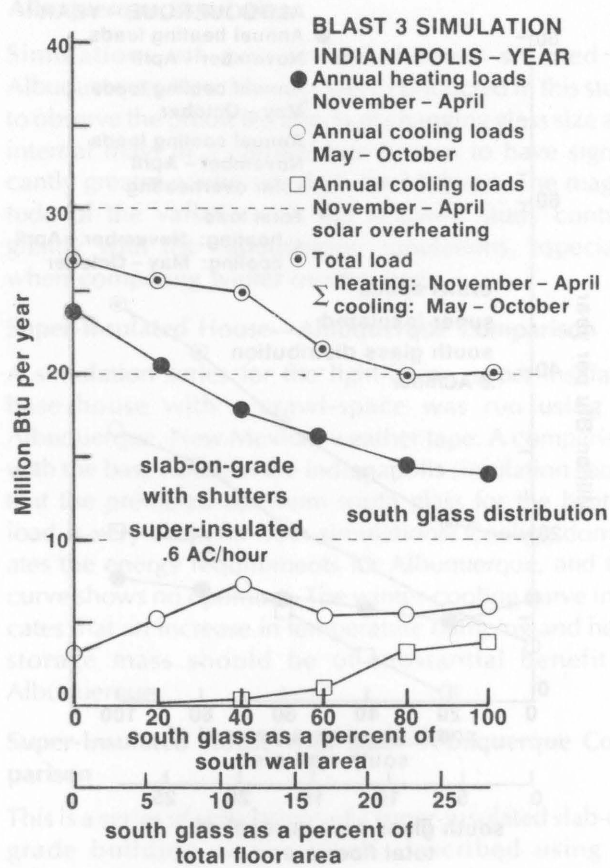


Figure 11. Super-Insulated House with Slab and Shutters

SUMMARY

Computer-simulated energy-use prediction programs have received increasing attention by architects and building designers as conventional energy sources become more expensive. The proposed national Building Energy Performance Standards (BEPS) placed great emphasis on computer-modeling of building performance. Direct-gain passive solar energy can be a powerful approach to decreasing the space conditioning energy used in a structure.

As progress is made in the energy-efficient design of buildings, it is becoming increasingly evident that a structure must be planned with the specific climate as a major factor. This is especially true when designing a building to receive passive-solar direct gain. Comparison of the Albuquerque simulations with those for Indianapolis reveals very different relationships between optimum south glass areas and excess winter heat. This demonstrates the need for simulation studies to be conducted for each specific climate-type in order to accurately estimate the effects of solar strategies on long-term energy use.

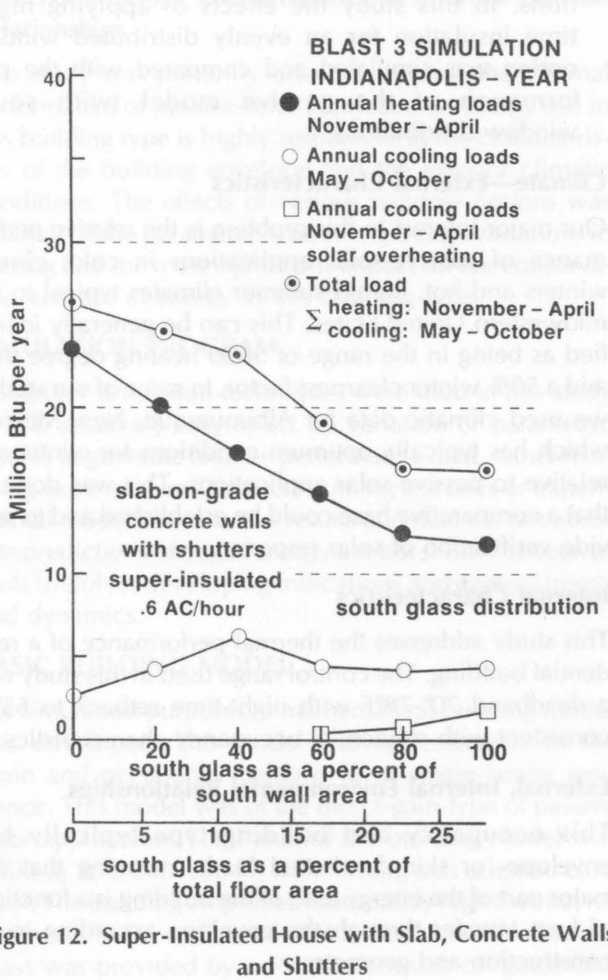


Figure 12. Super-Insulated House with Slab, Concrete Walls, and Shutters

The data produced would be valuable tools for an individual designing a similar or comparable structure in similar climatic conditions. Analysis of simulation results for a specific situation can lead the designer to develop and simulate more efficient approaches to solar-energy problems. Excessive heat loss from glazing during off-solar hours in the Midwest leads to ways of reducing those losses. Approaches such as variable thermal barriers can be tested initially by simulation techniques to predict relative benefits.

FURTHER RESEARCH

The Small Homes Council-Building Research Council is presently involved in a project to instrument two adjacent passive-solar homes designed and built according to the specifications for the University of Illinois Lo-Cal House. The data-collection process will span three years and be compared with simulated predicted performance data for these structures. Work is concerned with such subjects as direct solar gain, optimum infiltration-ventilation techniques, and heat flow through the wall insulation.

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The Effects of Night-Time Insulated Shutters on a Passive-Solar House

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Michael T. McCulley
Donald E. Bergeson

This paper was first presented at the 4th Miami International Conference on Alternative Energy Sources held on December 14-16, 1981, at Miami Beach, Florida, under the sponsorship of the Clean Energy Research Institute, University of Miami, in cooperation with the International Association for Hydrogen Energy.

ABSTRACT

This paper demonstrates the approach and orientation that the University of Illinois is employing to develop a detailed understanding of the principles of energy conservation and building design. Of primary interest in this research is the study of the dynamics of passive solar performance in cold, cloudy climate areas with less than optimum conditions for the use of passive solar design. This paper addresses the area of passive solar heating and the relative benefits of employing night-time shutters to maximize the solar benefit in cold, cloudy climate areas.

INTRODUCTION

Recent studies at the University of Illinois have indicated that the use of night shutters on south glass is necessary in order to significantly reduce heating loads by using solar energy in the midwestern United States. Unprotected south glass can be an overall net loser in such climates. The prime intention of the research was to study the performance of passive solar applications that use night shuttering techniques through the use of BLAST version 3, a computer-based thermal modeling program capable of modeling passive solar applications.

Specific areas covered in this paper concerning the use of night shuttering include:

- a comparative study of passive solar performance in two different climatic areas. This study was conducted to observe the differences in passive solar performance for a climate area characterized by cold, cloudy winter conditions and a climate area with relatively optimum conditions for passive solar.
- an annual thermal performance study with a monthly analysis directed toward understanding the dynamics of passive solar operation in the Midwest. This study introduces the concept of "solar benefit" and how it compares as an effective measure of passive performance the solar heating fraction.
- the effects of window distribution and energy conservation. This study was conducted to provide a comparative base for passive performance using optimum thermal resistance for night-time shutters. In this study the effects of using night shutters was simulated with varying thermal resistance of windows from R-0 to R-20.
- optimum glass area and thermal resistance of the night shutter. In this study the basic building model was simulated with varying areas of south glass with night shutters. The thermal resistance of this shutter was also varied in the simulation.
- the use of night-time shutters for retrofit applications. In this study the effects of applying night-time insulation for an evenly distributed window option was simulated and compared with the performance of the passive model (with south window distribution).

Climate—External Characteristics

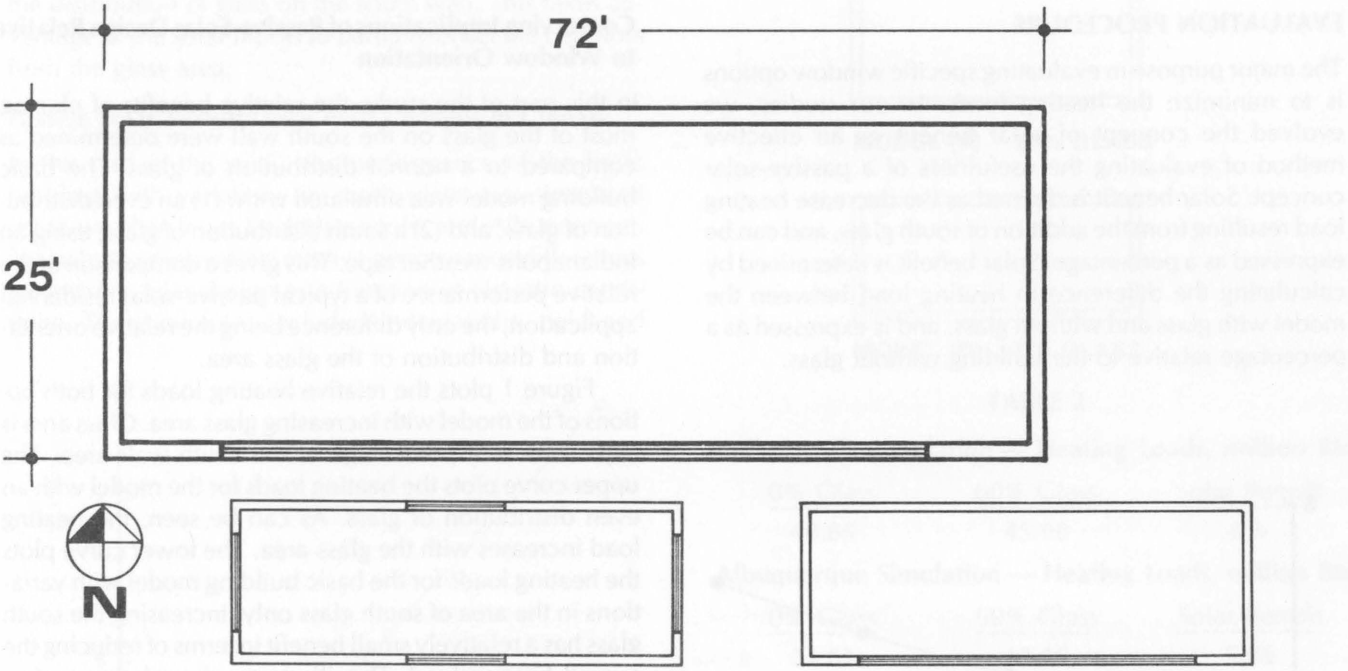
Our major interest in this problem is the relative performance of passive-solar applications in cold, cloudy winters and hot, humid summer climates typical to the midwestern United States. This can be generally identified as being in the range of 5600 heating degree days and a 50% winter clearness factor. In some of our studies we used climatic data for Albuquerque, New Mexico, which has typically optimum conditions for winter sun relative to passive-solar applications. This was done so that a comparative base could be established and to provide verification of solar response.

Internal Characteristics

This study addresses the thermal performance of a residential building. The control range used in this study was a deadband 70°-78°F with night-time setback to 65°F, consistent with residential occupancy characteristics.

External, Internal Environmental Relationships

This occupancy and building type typically has envelope- or skin-dominated loads, meaning that the major part of the energy load of the building is a function of heat transfer through the envelope according to its construction and geometry.



EVEN WINDOW DISTRIBUTION

SOUTH WINDOW DISTRIBUTION

Effects of Envelope Characteristics on Internal-External Relationships

This study was primarily oriented towards the thermal performance of passive-solar applications. Energy use in this building type is highly responsive to the characteristics of the building envelope and the exterior climatic conditions. The effects of various window options was studied. Of the parameters examined, design variations in glazing had the most significant impact on the conservation and use of energy in this building type.

SIMULATION PROGRAM

Computer simulation techniques were used in this study as it is relatively easy to set up variation or parametric studies to generate relative performance data, rather than using expensive and time-consuming test cells or experimental models. Simulation results and data are not absolute predictions of actual energy use but should be seen as tools useful for developing indications and general trends and dynamics.

BASIC BUILDING MODEL

For simulation purposes, a mathematical building model was developed. This model was representative of the scale and occupancy patterns for a single-family residence. This model was of the direct-gain-type of passive solar application. Total area of the building model was 1800 sq. ft. (72 ft. x 25 ft.) with its long axis oriented east/west. The building employed moderately high thermal resistance—R-20 walls and R-40 roof. Interior thermal mass was provided by a 6″ concrete slab on grade (the slab was dissociated from the effects of ground coupling). Total interior mass for the building provided by the slab at 140 lb. per cubic foot was 126,000 lb. The building employed only south-facing glass (except in specific comparative studies).

PROCEDURE

This research was directed towards determining the effects of specific glazing options on the thermal performance for passive-solar applications. The effort was directed towards exploring static modifications for window design to minimize heat loss. Static modifications in this study refers to the variation of area, type, and orientation of glass employed on the building, while dynamic modifications refer to the use of night shutters to provide selective insulation of the glass area to reduce night-time heat losses.

TABLE 1. DESCRIPTION OF BUILDING SURFACES

	Area	U-value	Azimuth°	Tilt°
Exterior Wall (variable)	235.4	.049	180	90
Window at 60%	351.7	.553	180	90
Exterior Wall	196.0	.049	90	90
Exterior Wall	587.2	.049	0	90
Exterior Wall	196.0	.049	270	90
Slab-on-grade	1800	.050	0	0
Roof	1800	.025	0	0

EVALUATION PROCEDURE

The major purpose in evaluating specific window options is to minimize the heating loads. In our studies, we evolved the concept of solar benefit as an effective method of evaluating the usefulness of a passive-solar concept. Solar benefit is defined as the decrease heating load resulting from the addition of south glass, and can be expressed as a percentage. Solar benefit is determined by calculating the difference in heating load between the model with glass and without glass, and is expressed as a percentage relative to the building without glass.

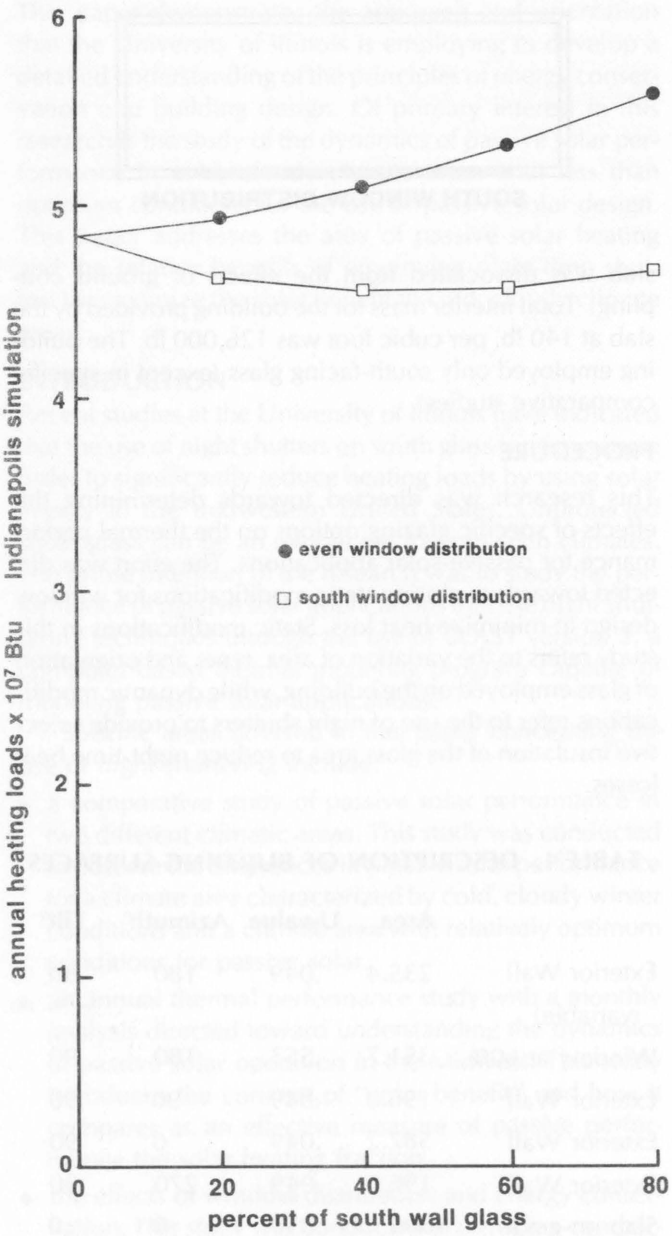


Figure 1

Conserving Implications of Passive-Solar Design Relative to Window Orientation

In this part of the study, the relative benefits of placing most of the glass on the south wall were determined as compared to a normal distribution of glass. The basic building model was simulated with: (1) an even distribution of glass, and (2) a south distribution of glass, using an Indianapolis weather tape. This gives a comparison of the relative performance of a typical passive-solar residential application, the only difference being the relative orientation and distribution of the glass area.

Figure 1 plots the relative heating loads for both options of the model with increasing glass area. Glass area is expressed as a percentage of the south wall area. The upper curve plots the heating loads for the model with an even distribution of glass. As can be seen, the heating load increases with the glass area. The lower curve plots the heating loads for the basic building model with variations in the area of south glass only. Increasing the south glass has a relatively small benefit in terms of reducing the overall heating load. This illustrates the relative performance of direct-gain systems in climatic areas with less than optimum conditions of winter sun. In terms of energy conservation, there are specific benefits in concentrating

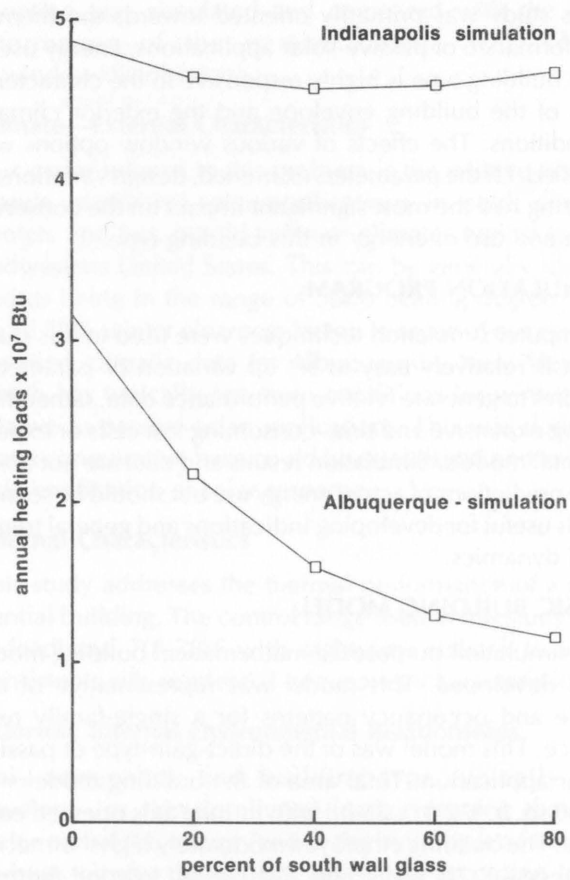
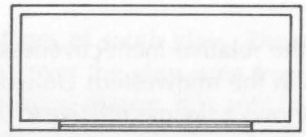


Figure 2

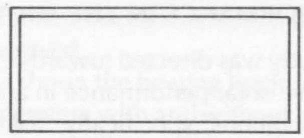
the distribution of glass on the south wall. This takes advantage of the solar inputs to partially offset the heat-loss from the glass area.

Passive Solar Performance with Changes in Climate

In this part of the study, the performance of the basic building with variations in south glass was simulated using weather tapes for Indianapolis and Albuquerque. This was to compare the relative performance differences for passive-solar design as a function of climatic conditions. These climates included Indianapolis, cold and cloudy, with less than optimum conditions for passive-solar applications; and Albuquerque, cold and clear, with relatively good conditions for passive-solar applications.



MODEL (A) 60% GLASS



MODEL (B) 0% GLASS

TABLE 2

Indianapolis Simulation — Heating Loads, million Btu

0% Glass	60% Glass	Solar Benefit
48.85	45.98	6%

Albuquerque Simulation — Heating Loads, million Btu

0% Glass	60% Glass	Solar Benefit
31.61	13.19	58%

Figure 2 plots the relative performance of the building model with south glass only (operating in a passive direct-gain mode) for the two climatic areas. The results indicate a much greater response or sensitivity to increasing glass area for Albuquerque than for Indianapolis.

THE RELATIVE PERFORMANCE EVALUATION OF USING SINGLE, DOUBLE, AND TRIPLE GLASS IN COLD, CLOUDY WINTER CLIMATES

This part of the study was to explore the relative performance of glazing in passive-solar applications. The building model was simulated with varying percentages of single, double, and triple south glass using the Indianapolis weather tape.

Figure 3 shows the heating loads for the building model employing single, double, and triple glass for Indianapolis. Heating loads for the single glass increase greatly as a function of increasing glass area. The use of double glass makes a substantial reduction in heating load as compared to the single-glazed model. However, the overall solar benefit with double glass is relatively

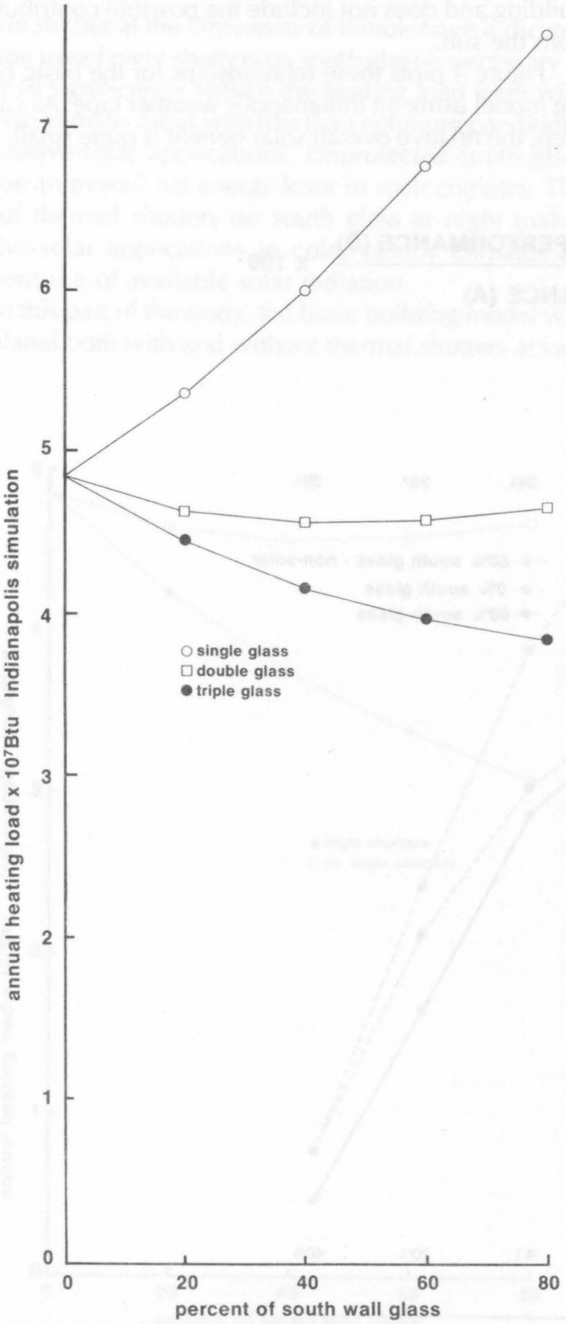


Figure 3

TABLE 3. Performance with 60% South Glass

Glazing	Heating Load million Btu	Percent Improvement	Solar Benefit
Single	67.76	-	-38%
Double	45.98	32%	6%
Triple	39.71	13%	18%

small, indicating the relative ineffectiveness of passive-solar applications in the midwestern United States. The use of triple glass shows a savings relative to double glass. The solar benefit also increases relative to double glass.

PERFORMANCE STUDY WITH A MONTHLY ANALYSIS OF PASSIVE PERFORMANCE IN THE MIDWEST

This part of the study was directed towards exploring the dynamics of passive-solar performance in areas with less than optimum conditions, specifically, the midwestern United States. Three building model types were used in this part of the study. Model A was programmed to operate in passive direct-gain mode and had 60% south glass; Model B had no south glass; Model C had 60% south glass; however, the relative solar inputs were not included in this simulation model (non-solar).

Two basic quantification methods were used. *Solar benefit* compares the thermal performance of Model A and Model B. The percentage decrease in the heating load as compared to Model B represents the relative overall benefit from the addition of south glass to admit sunlight.

Solar heating fraction compares the thermal performance of Model A and Model C. The percentage decrease in the heating load from Model A as compared to Model C represents the relative contribution due to solar inputs. The performance of Model C represents the heating load of the building as a function of heat loss from the building and does not include the possible contributions from the sun.

Figure 4 plots these relationships for the basic building model using an Indianapolis weather tape. As can be seen, the relative overall solar benefit is quite small, on a

$$\text{SOLAR BENEFIT} = \frac{\text{PERFORMANCE (A)} - \text{PERFORMANCE (B)}}{\text{PERFORMANCE (A)}} \times 100$$

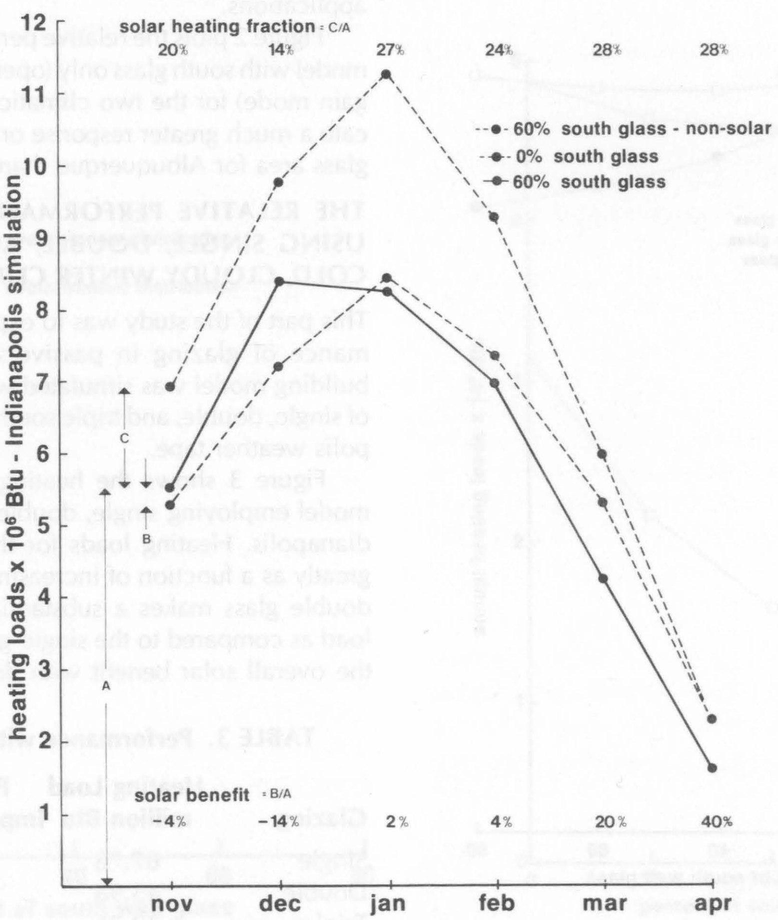


Figure 4

monthly basis. Solar benefit varies as a function of changing monthly climatic conditions. Using the solar heating fraction method indicates much higher percentages, and this is a useful measure in terms of identifying the proportion of the overall heating load that is provided by solar. However, in terms of understanding and comparing solar performance and the relative conservation implications of glass, the solar benefit measure provides a more realistic view, since it takes into account the losses from the structure caused by the addition of the glass.

INSULATED NIGHT SHUTTERS

Recent studies at the University of Illinois have indicated that the use of night shutters on south glass is necessary in order to significantly reduce the heating load from windows in climatic areas with less than optimum conditions for passive-solar applications. Unprotected south glass can be an overall net energy loser in such climates. The use of thermal shutters on south glass at night makes passive-solar applications in cold, cloudy climates an efficient use of available solar radiation.

In this part of the study, the basic building model was simulated both with and without thermal shutters at various percentages of south glass. The shutters were programmed to cover the glass area from sunset to sunrise during the heating season. It is anticipated that selective closure during cloudy periods would provide additional benefits. This possibility, however, was not included in this study. Indianapolis and Albuquerque weather tapes were used so that climatic differences in performance could be observed.

Figure 5a shows the heating loads for the basic building model operating with and without night-time thermal shutters using an Indianapolis weather tape. Increasing glass area has relatively little benefit in terms of reducing the heating load when operating without thermal shutters.

Figure 5b plots the heating loads for the basic building model with and without thermal shutters using an Albuquerque weather tape. Increasing glass area has a significant effect in terms of reducing the heating load. The solar benefit is substantially greater for the purely passive model when compared with the performance in Indianapolis. Thermal shutters provide additional savings. However, the actual Btu saving of using shutters in Albuquerque is not as great as it is in Indianapolis.

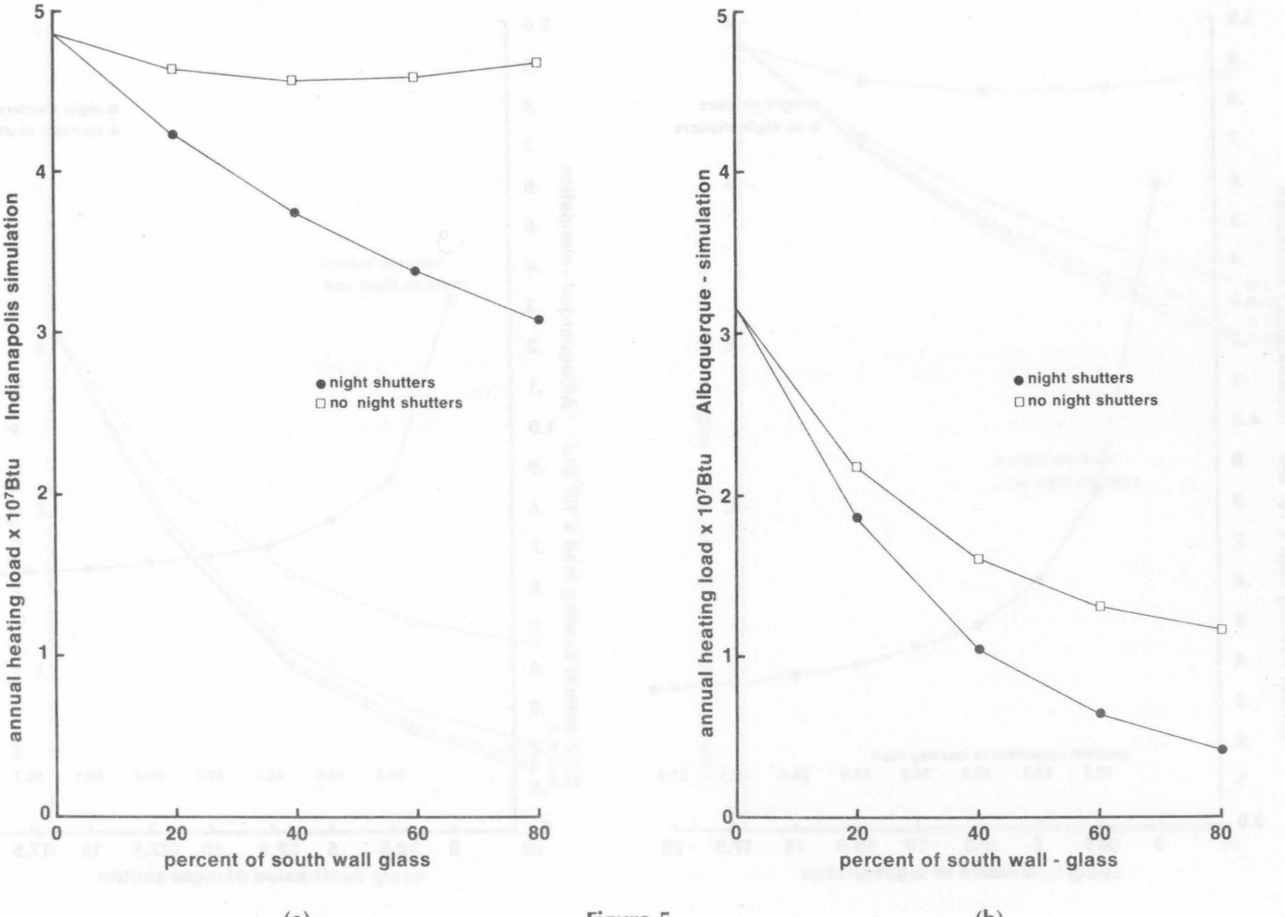


Figure 5

TABLE 4. Indianapolis

	Heating Load, million Btu		
	0% Glass	60% Glass	Solar Benefit
No night shutters	48.85	45.98	6%
R-15 night shutters	48.85	33.82	30%

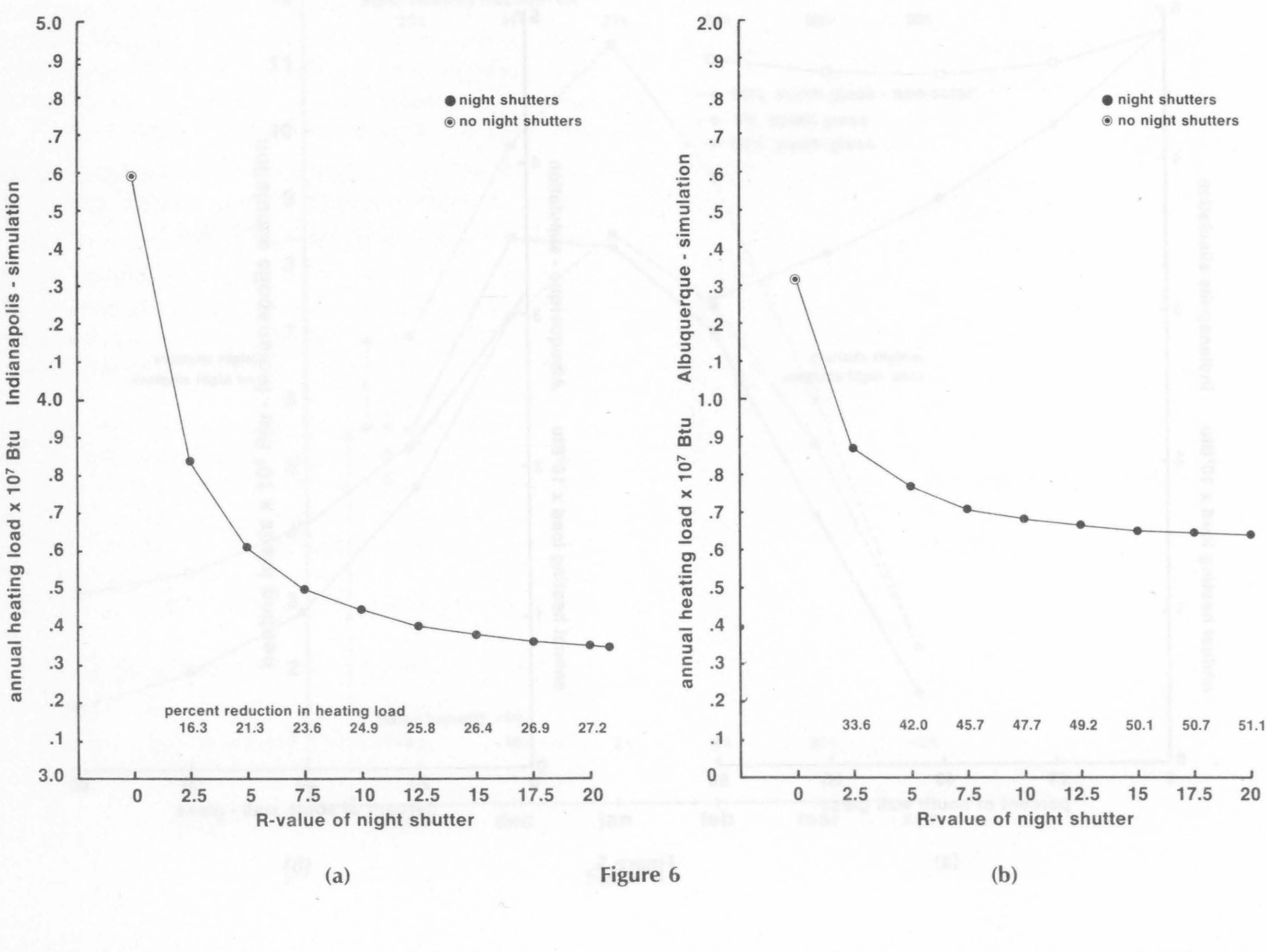
OPTIMIZING THERMAL RESISTANCE FOR NIGHT-TIME SHUTTERS

Night-time insulation should be considered an integral part of passive-solar systems operating in climatic areas with less than optimum conditions for passive solar applications. One of the central questions in development of night shuttering systems has been the determination of the optimum insulating value. This could influence greatly the type of system in terms of detailing, operation, durability, and, more importantly, cost. In the first part of the study, the basic building model employing 60% of the south wall glass was simulated with and without thermal shutters. The thermal resistance of the shutter was varied from R-0 to R-20.

TABLE 5. Albuquerque

	Heating Load, million Btu		
	0% Glass	60% Glass	Solar Benefit
No night shutters	31.61	13.19	50%
R-15 night shutters	31.61	6.58	79%

Figure 6 shows the heating loads for the building model at 60% south glass while varying the insulating value of the shutter. The percent decrease in heating load as compared to the building operating without shutters has been included on the graph. Significant reductions in the heating load diminish quite quickly after R-10 to R-12 in the Indianapolis simulation. Similar diminishing returns occur in the range of R-5 to R-7.5 in the Albuquerque simulation. (The change in slopes of the two curves should be compared to indicate relative optimum ranges.) Night insulation tends to be more effective in terms of Btu savings in the Indianapolis simulation. In terms of reducing the overall heat load, night shutters are more effective on a percentage basis in Albuquerque.



(a) **Figure 6** (b)

OPTIMUM GLASS AND NIGHT-TIME SHUTTERS

In the next part of this study, the basic building model was simulated varying the thermal resistance of the shutter and with various amounts of south glass. Figure 7 shows the heating loads for the basic building model at varying amounts of south glass. The insulating value of the shutter was simulated at R-5, R-10, R-15, and R-20. The most significant reduction in heating loads occurs with R-5 night insulation for both climatic areas. An R-10 shutter produces an additional savings for both climates. This savings is slightly greater in Indianapolis than in Albuquerque.

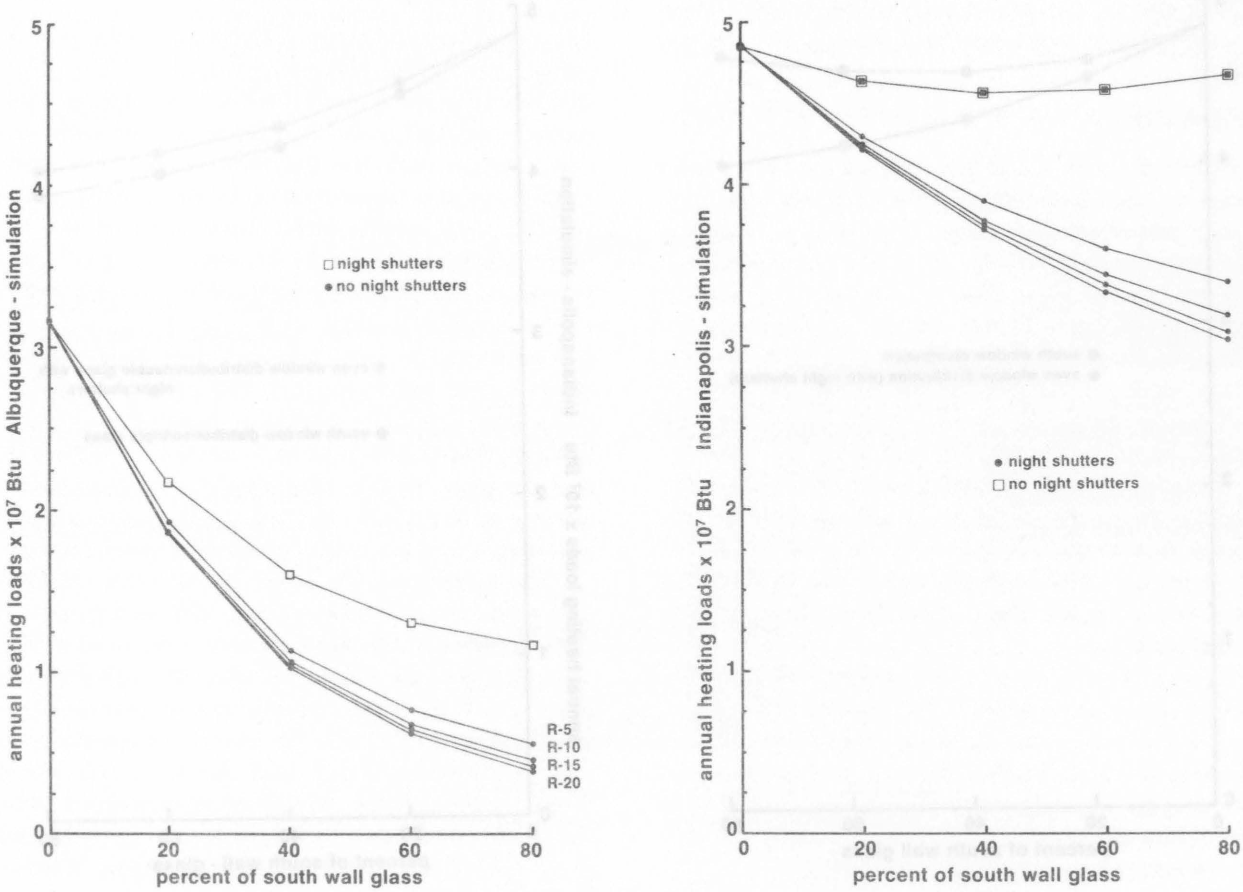
INSULATED NIGHT-TIME SHUTTERS FOR RETROFIT

In this part of the study, the relative benefits of applying night shutters in retrofit applications was explored. This conservation method can have significant benefits for existing buildings that may not have the geometry for passive-solar applications. This study compares the performance of an evenly-distributed-window model with the performance of the model with south distribution of windows. The model with south window distribution represents a passive-solar application and the model with an even distribution of windows represents a conventional design.

Figure 8 shows the heating loads for the building model with a south distribution of windows (double glass), and an even distribution of windows with night insulation (double glass). The south-oriented-glass model represents the performance of a conventional passive-solar application. As can be seen, the model with evenly distributed glass out-performs the passive model when night-time shutters are used. This demonstrates the potential of retrofitting homes that have evenly distributed windows.

Figure 9 plots the heating loads of the building model with an even distribution of windows with night insulation (double-glass), and a south distribution of windows (triple-glass).

This compares the performance of the building model operating in a passive-gain mode with the model with evenly distributed glass and night shutters. There is a relatively small difference in the performance of the two models. Triple-glass with south distribution has a small advantage over the model with even window distribution. This study adds further support to the potential of using night-time shutters in retrofit applications.



(a) Figure 7 (b)

Much attention has been given to increasing the area of south glass. In retrofit or upgrading applications, this could prove to be a very expensive alteration. The use of night-time shutters could provide an inexpensive alternative that would produce comparable performance. In new design, major decisions are made to maximize south glass. On a performance basis, shuttering the more-typical window distribution types will produce similar results when compared to the purely passive mode of operation.

SUMMARY AND CONCLUSIONS

One of the most important conclusions in this study is that it is important to recognize regional climatic differences in the evolution of an energy-conserving building form, and that specific geometries applied in one climatic area may not produce the same level of expected response in other areas. This applies specifically to the development of passive-solar applications and in recognizing their relative performance capabilities.

Using passive-solar techniques in climatic areas with less-than-optimum conditions requires a very careful design of the building envelope. Passive-solar applications in the Midwest do not provide the same level of performance as is obtained in climatic areas such as the south-western United States. This is primarily a function of the relative availability of winter sun. Typically, the Midwest experiences relatively cloudy winter conditions. The limited winter sun, in conjunction with high winter temperature differentials, results in a reduced performance. The intelligent application of passive-solar principles can result in conservation benefits in areas that experience less than optimum conditions, such as the specific advantages associated with a south distribution of glass.

This research indicates that in order to maximize the conservation potential associated with a south distribution of glass, it is necessary to insulate the south windows on a selective and variable basis, especially in cold, cloudy climates.

Night-time shuttering techniques using relatively moderate insulating materials (R-5 to R-10) can provide significant benefits. This study made use of a large, hourly computer simulation program and demonstrates the potential of simulation techniques to develop comparative performance data to be used in the design and evolution of a specific application.

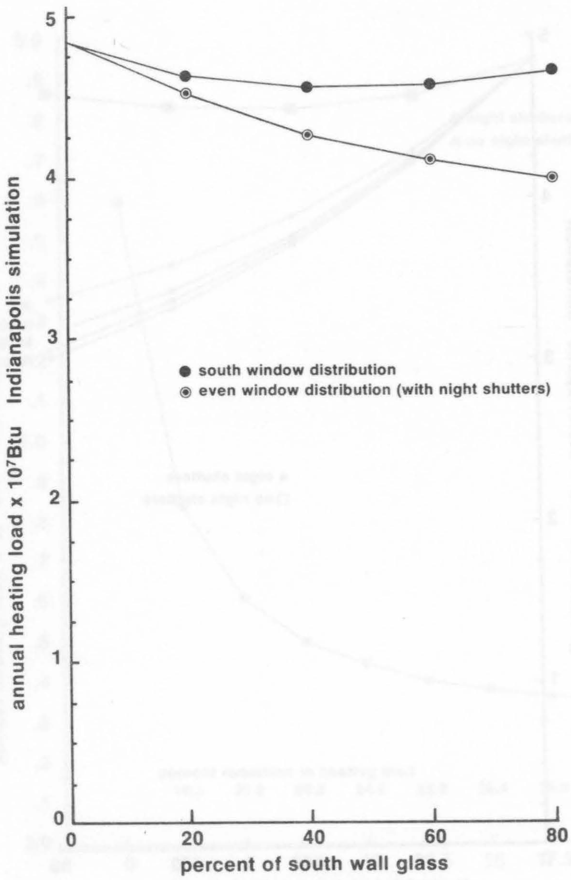


Figure 8

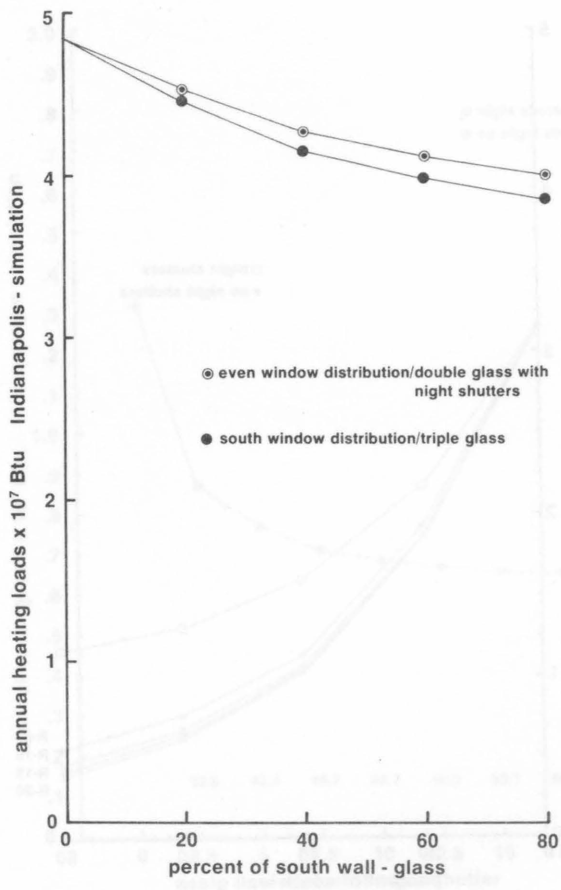


Figure 9

ACKNOWLEDGEMENTS

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The Effect of Overhangs and Day-Time Insulated Shutters on Summer Cooling

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Donald E. Bergeson
Michael T. McCulley

This paper was first presented at the 4th Miami International Conference on Alternative Energy Sources held on December 14-16, 1981, at Miami Beach, Florida, under the sponsorship of the Clean Energy Research Institute, University of Miami, in cooperation with the International Association for Hydrogen Energy.

ABSTRACT

This paper demonstrates in part the approach used at the University of Illinois to develop a more detailed understanding of the principles of energy conservation and building design. Of primary interest in this research is the study of the dynamics of passive-solar performance in climatic areas with cold, cloudy winters and hot, humid summers. Such regions exhibit conflicting seasonal requirements for sizing of solar apertures. This paper addresses the area of passive cooling and thermal performance, including the study of the relative benefits of overhangs and the use of daytime shutters for the thermal protection of the solar aperture during the cooling season.

INTRODUCTION

One of the most critical and ignored problems associated with passive-solar applications is the relatively high cooling loads that result from large areas of glass typically found on the south face of the building. These relatively large areas of south glass allow the sun to shine into the space in the heating season to reduce heating loads, but the glass also allows for solar intrusion during the cooling season, creating conductive, convective, and radiant gain. Cooling loads in passive applications can be as high as the heating loads. The responsibility of the designer includes not only providing effective passive solar comfort for the heating season, but also to provide thermal protection to the occupants in the cooling season. The primary objective in this research was to study the problem of cooling and thermal performance in passive-solar applications.

This study is directed towards understanding the implications and relative impacts that glazing can have on thermal performance for building types with skin- or envelope-dominated loads. Thermal performance for this building-type is highly dependent on the composition and geometry of the envelope. Energy transfer through the envelope in terms of heat loss and heat gain is a function of interior comfort conditions, exterior climatic conditions, and the relative composition of the envelope.

Computer simulations were used in this study, as it is relatively easy to set up variation studies and generate performance data, rather than using expensive and time-consuming test cells or experimental models. Simulation results and data are not absolute predictions of actual energy use, but should be seen as tools, useful for developing indications and general trends and dynamics. It should be noted that BLAST simulation techniques are fairly comprehensive and have been shown to be quite accurate in test-cell verification studies.

DESCRIPTION OF THE BASIC BUILDING MODEL

For simulation purposes, a building model was developed. This model was representative of the scale and occupancy patterns for single-family residences, and residential occupancy and lighting schedules were used in conjunction with the building model. The building model was also representative of the direct-gain-type of passive-solar application. Total area of the model was 1,800 sq. ft.(72 ft. x 25 ft.), with its long axis oriented east-west. The building employed moderately high thermal resistance — R-20 walls and R-40 roof. Interior thermal mass was provided by a 6-inch concrete slab-on-grade floor at 140 lb-cu. ft. or 126,000 lbs. (The slab was dissociated from the effects of ground coupling.) The building employed exclusively south-oriented windows, and the glass area in these studies was expressed as a percent of the south wall area. A complete description and diagram of the building model is given on page 21.

The envelope is the major element that modifies the transfer of energy between the conditioned space and the outside climate. The local climate is the primary driving force that generates energy transfer through the building envelope. Temperature difference and solar radiation are the significant factors in the transfer of energy between the conditioned space and the outdoors for skin-dominated buildings. Temperature difference between the conditioned space and outside is the climatic variable in the basic equation for describing heat loss. Solar radiation can have significant impacts on the building envelope in terms of heating and cooling loads.

Infiltration loads as a result of variable occupancy habits can be the greatest single contributor to both heating and cooling loads. In this study, however, infiltration was held constant to more clearly illustrate the effect of variations in other parameters.

The primary factor in designing the building envelope for energy conservation is to minimize the heating and cooling loads resulting from energy transfer. Window design has significant effects on the thermal performance of the building envelope. Glazing materials typically have low thermal resistances and high transmission values. (A double-glazed surface loses more than 10 times as much heat as an equal area of insulated wall.) The window element is highly responsive to temperature differentials, generating heat loss and heat gain. It is also highly responsive to solar and radiant transfer. Passive-solar techniques make use of this fact by utilizing relatively large areas of glazing with south orientation. This allows for solar penetration into the space to reduce the heating loads.

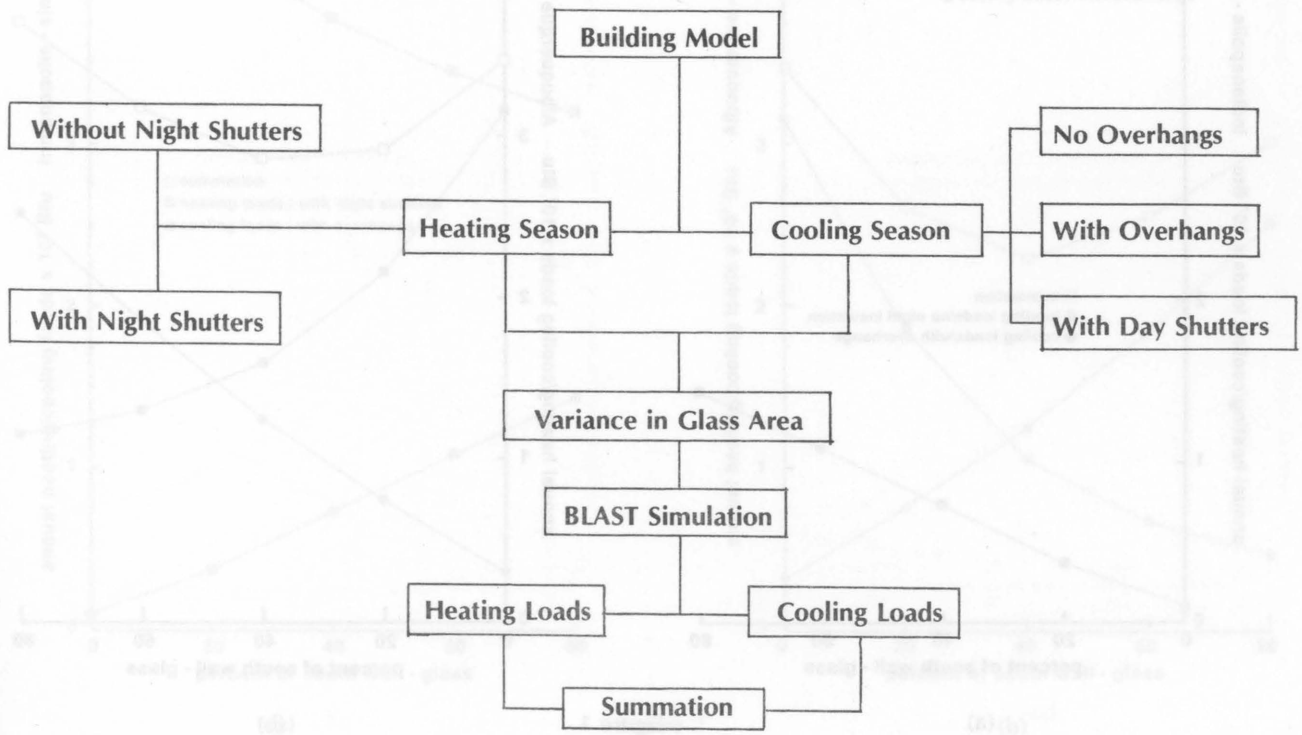
Overall, glazing is the critical element in the composition of the building envelope in terms of energy transfer. In this study, the relative effects of glazing were studied in terms of heat gain and heat loss on a seasonal basis, directed towards optimizing the use of glass in skin-dominated buildings. Optimization of glass for the building envelope is a function of two basic parameters: 1) minimize heat loss from the glazed surface during the heating season, 2) minimize heat gain through the glazed surface during the cooling season.

The first part of this research was directed towards determining the effects of glazing on thermal performance in the heating season, and towards studying methods of minimizing heat loss resulting from the glazing. This effort was directed towards exploring static modifications for window design to maximize conservation benefits and to explore dynamic modifications for window design to minimize heat loss. Static modifications in this study refers to the variation of area, type, and orientation of glass employed on the building. Dynamic modifications refer to the use of night shutters to provide selective thermal closure of the glass area to reduce heat loss.

The second part of this research was directed towards studying the effects of glazing on thermal performance during the cooling season and with evaluating various methods of reducing cooling loads associated with the use of glass. Static and dynamic modifications were considered in this part of the study as well. Static modification refers to variations in the area of glass and methods of thermal protection (specifically, overhangs). Dynamic modification refers to the use of day shutters to provide thermal protection to the glass area during the cooling season.

PROCEDURE

The following is an outline of the overall method developed in this study. The basic building model was simulated with various options for the treatment of the windows. For each option, the size of the south-facing windows was varied, with the variance expressed as a percent of the south wall, ranging from 0% to 80% glass.



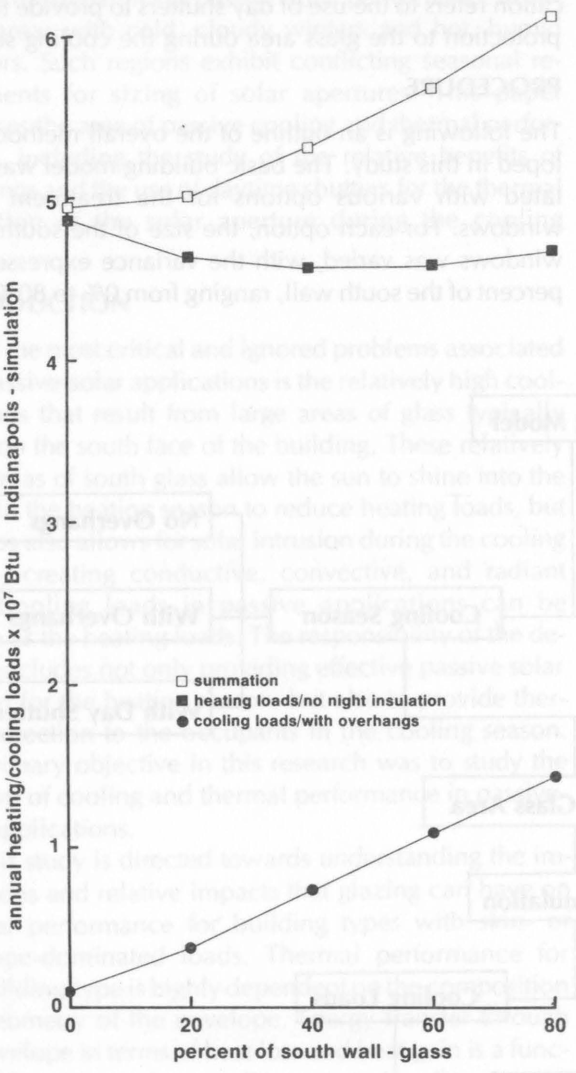
Three basic options for the treatment of the south-facing windows were considered. The first option represents a conventional passive-direct-gain building with overhangs during the cooling season. The second option employs night shutters to maximize solar benefit during the heating season and to shade the windows during the cooling season. The third option employs night shutters during the heating season, reverses the action of these shutters to become day shutters during the cooling season, and does not use overhangs.

FIRST OPTION

In this part of the study, the basic building model was programmed to operate in a passive direct-gain mode without employing night-time window insulation. The building incorporated horizontal overhangs to shade the south windows during the cooling season. The thermal performance of the building model was determined for both the heating and cooling season and plotted as a function of increased south glass area. A summation of heating and cooling loads for each area of glass simulated represents an overall energy-use curve illustrating the conservation implications associated with increasing glass area.

OVERVIEW

Figure 1a plots the heating and cooling loads for the range of 0% to 80% of the south wall in glass for the building model using an Indianapolis weather tape. The summation curve represents the combined performance (heating and cooling) as a function of increasing glass area. The heating curve illustrates the relative performance of direct-gain systems in climates with less than optimum conditions for winter sun. Increasing the area of glass has a relatively small benefit in terms of reducing the overall heating load. The cooling curve represents the cooling loads as a function of increasing glass area, and shows that cooling loads increase greatly as a function of increasing glass area. The summation curve represents the performance combination in terms of heating and cooling. The combined heating and cooling load increases as a function of increasing glass area, establishing that cooling loads in passive-solar applications can be a prime factor with respect to the overall energy performance.



(a)

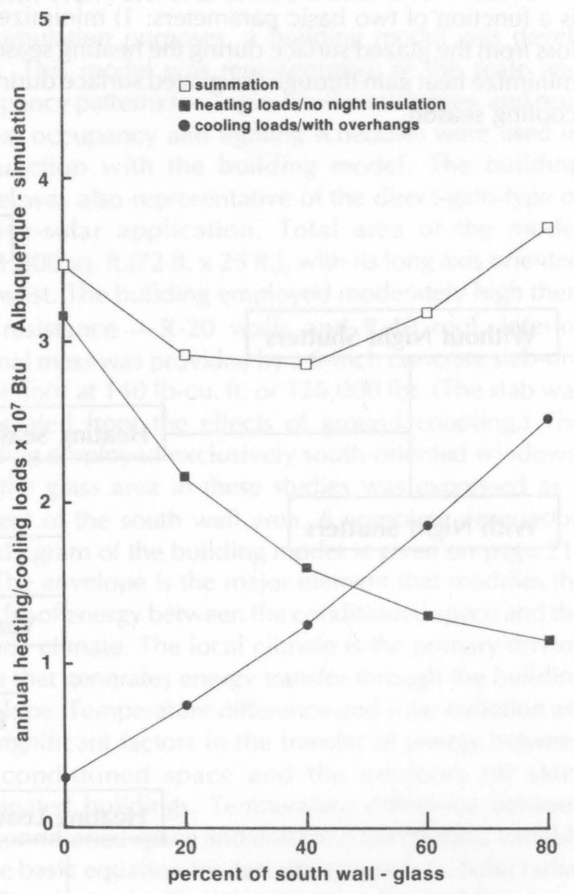


Figure 1

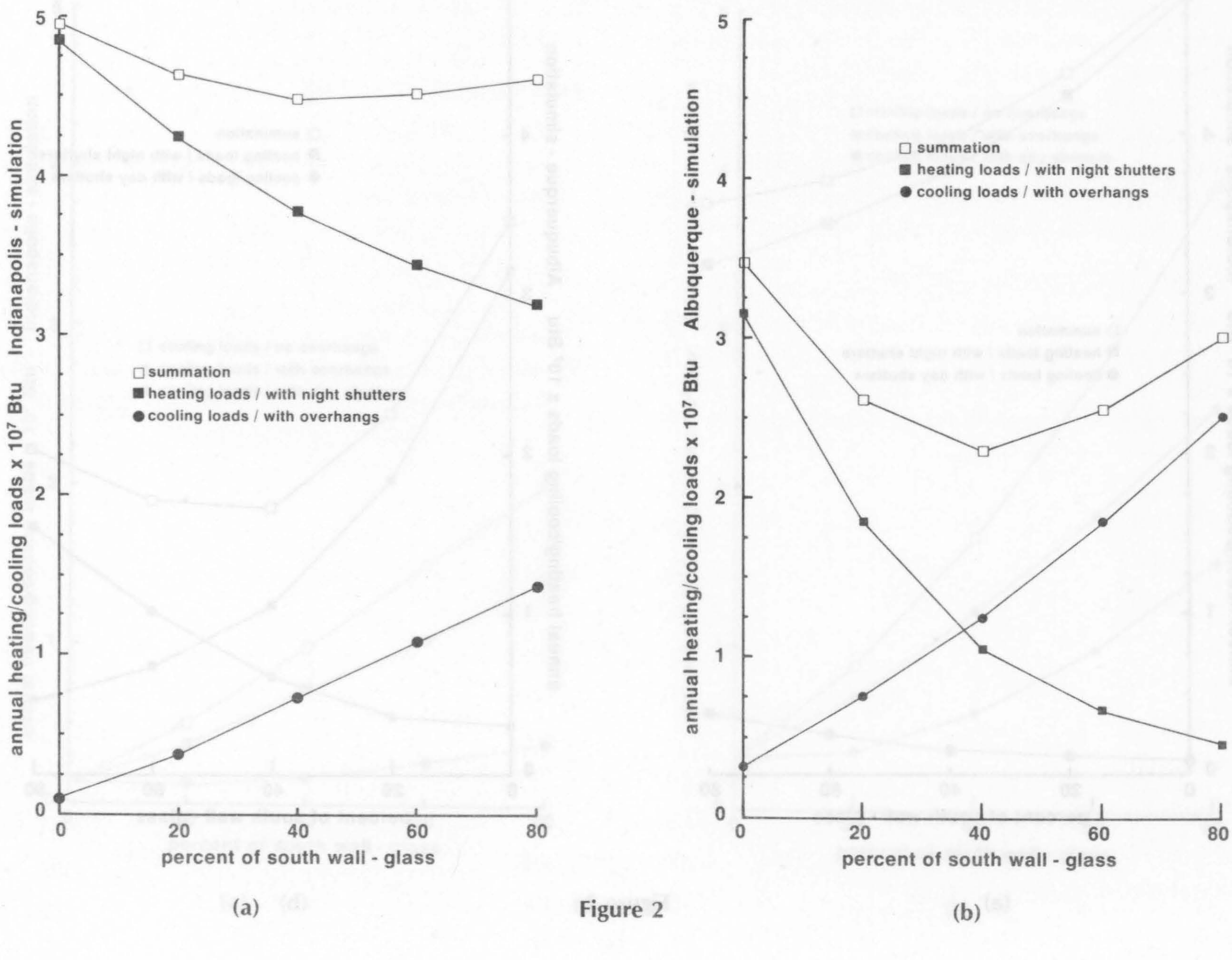
(b)

Figure 1b plots the heating and cooling loads for the range of 0% to 80% of the south wall in glass for the building model using an Albuquerque weather tape. The heating curve illustrates the relative performance of direct-gain applications in climatic areas with nearly optimum conditions for winter sun. Increasing south glass area has significant benefits in terms of reducing the heating load. The cooling curve represents the cooling loads as a function of increasing glass area and, as can be seen, cooling loads increase greatly as a function of increased glass area. Cooling loads in this climatic area can be as large or larger than the heating loads. The cooling load is as large as the heating load in the range of 40% to 45% south glass. The summation curve represents the performance combination in terms of heating and cooling as a function of increasing glass area. Increasing glass area above 40% of the south wall would represent a net loss in overall performance. In this climatic area, this building type has an optimum glass area in the range of 40% of the south wall. Cooling loads can have significant implications in terms of the desirability of large areas of south-wall glass.

SECOND OPTION

In this part of the study, the basic building model was programmed to operate in a passive direct-gain mode employing night-time insulated shutters. Recent studies have indicated that night shutters are a necessity in order to realize significant benefits from solar contribution in cold, cloudy climates. An R-15 night shutter was used to cover the window at night to minimize night-time loss during the heating season. The building used conventional horizontal overhangs to shade the south window during the cooling season. The thermal performance of the building model was determined for both the heating and cooling season for Albuquerque and Indianapolis.

Figure 2a plots the heating and cooling loads for the range of 0% to 80% of the south wall in glass for the building model using an Indianapolis weather tape. The summation curve represents the combined performance (heating and cooling) as a function of increasing glass area. The heating curve illustrates the relative performance of direct-gain application incorporating night shutters. As can be seen, night shutters provide an increase in performance in terms of reducing the heating load (compare with Figure 1). Increasing the glass area has significant benefits in terms of reducing the overall heating load. The cooling curve represents the cooling loads as a function of increasing glass area. Overhangs provide partial thermal protection to the windows during



(a) **Figure 2** (b)

the cooling season but cooling loads increase as a function of increased glass area. The summation curve represents the performance combination in terms of heating and cooling as a function of increasing glass area.

Increasing glass area has a relatively small benefit in terms of the overall performance of the building model since the high cooling loads resulting from the increased glass has a significant effect on the overall performance.

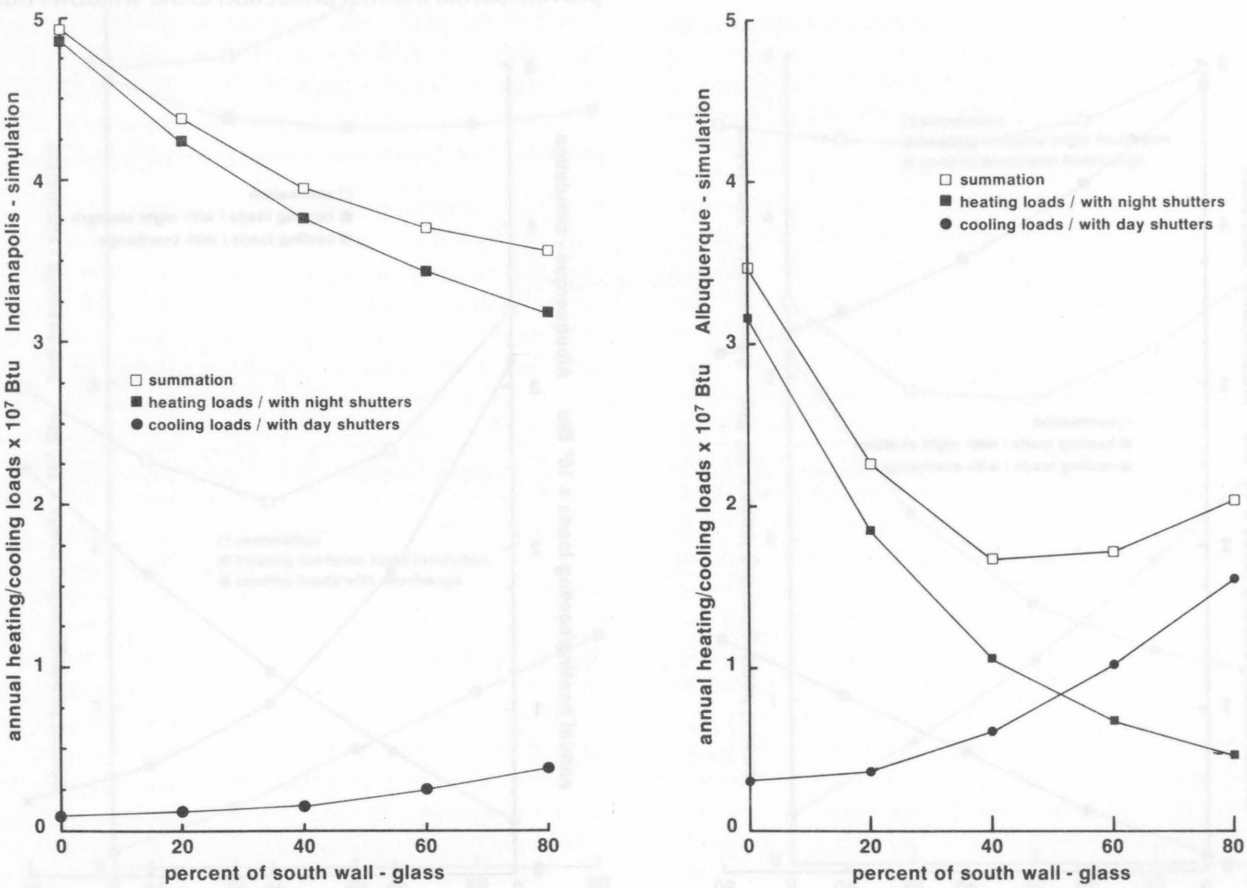
Figure 2b plots the heating and cooling loads for the range of 0% to 80% of the south wall in glass for the building model using an Albuquerque weather tape. The heating curve illustrates the relative performance of direct-gain applications incorporating night shutters. The addition of night shutters significantly reduces the heating load of the building model with increasing glass area; however, cooling loads increase greatly as a function of the increasing glass area. The summation curve represents the combination of heating and cooling loads and illustrates the overall performance with increasing glass area. The summation load decreases with increasing glass to the range of 40% south glass. Beyond 40% glass, the enlarged demand for cooling decreases the overall annual performance.

THIRD OPTION

In this part of the study, the basic building model was programmed to operate in a passive direct-gain mode using insulated shutters to minimize night-time loss during the heating season. The action of the thermal shutters was reversed for the cooling season. During the day, the thermal shutters would insulate the windows, minimizing heat gain through the glazing material. At night the shutters would be opened, allowing for radiant and conductive transfer to promote passive cooling. This option did not include the use of overhangs.

OVERVIEW

Figure 3a plots the heating and cooling loads for the range of 0% to 80% of the south wall in glass for the building model using an Indianapolis weather tape. The summation curve represents the combined performance (heating and cooling) as a function of increasing glass area. The heating curve illustrates the relative performance of direct-gain systems employing night shutters in climatic areas with less than optimum conditions for passive solar. Increasing glass area has specific advantages in terms of



(a) Figure 3 (b)

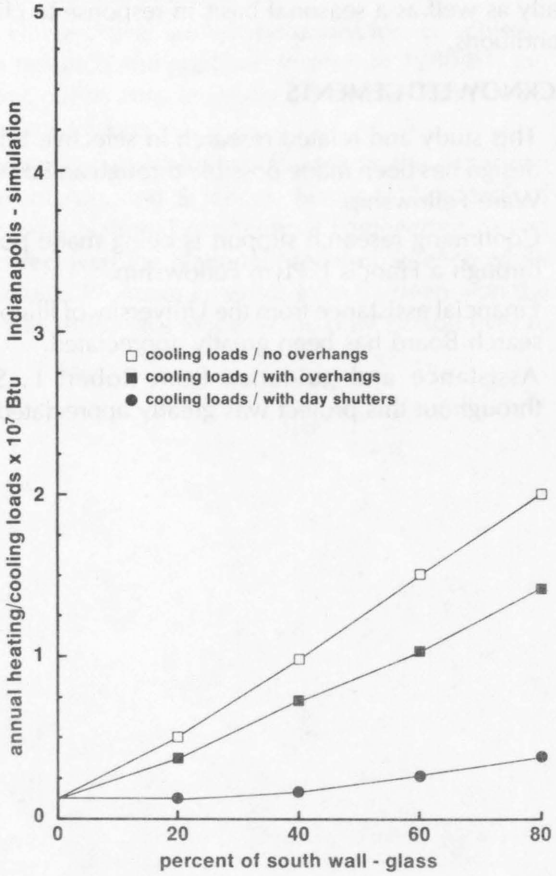
reducing the heating load. The cooling curve represents the cooling loads as a function of increasing glass area, employing day shutters for the thermal protection of the south windows during the cooling season. Using day shutters significantly reduces the cooling loads associated with the south glass area. The summation curve represents the performance combination for heating and at the range of glass area studied, and shows that increasing glass area can have benefits in terms of reducing the annual load of the building if the glass area is properly protected with day shutters during the cooling season.

Figure 3b plots the heating and cooling loads for the range of 0% to 80% of the south wall in glass for the building model using an Albuquerque weather tape. The heating curve illustrates the relative performance of a direct-gain application incorporating night shutters. The cooling curve represents the cooling loads as a function of increasing glass area employing day shutters during the cooling season. There is an increase in overall performance with increasing glass area, with an optimum range occurring at 40% south glass.

A THERMAL PERFORMANCE STUDY OF THE RELATIVE EFFECTS OF USING OVERHANGS AND DAY SHUTTERS FOR THE COOLING SEASON

In the three-part study presented above, the central element that determines the overall performance with increasing glass areas has been shown to be the cooling loads. Cooling loads resulting from the south glass are the predominant influence on the relative effectiveness of window sizing in both climatic areas. This suggests that an effective means should be found to reduce solar gains during the cooling season. In the continuation of the three-part study, the relative effectiveness of using overhangs and day shutters was explored. The building model was simulated without overhangs, with overhangs, and with daytime insulated shutters for the cooling season only. The shutters are closed during the day and opened at night during the cooling seasons.

Figure 4a, a continuation of the Indianapolis study, plots the cooling loads for the basic building model operating with overhangs, without overhangs, and with day



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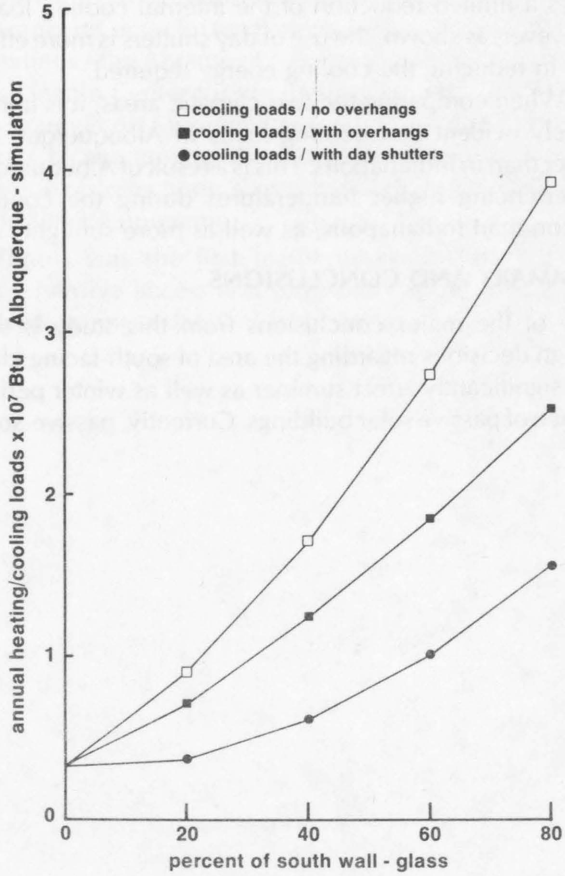

(b)

Figure 4

shutters for the cooling season. Cooling loads increase greatly with corresponding increases in glass area for the unprotected model. Overhangs are capable of shading the aperture area from direct-beam radiation for a specific time during the cooling season. Horizontal overhangs can reduce the cooling load by 20%—30% in comparison with the unprotected model. The overhang is limited in its shading potential in late summer and fall, when the solar geometry is such that horizontal screening is ineffective. In addition, overhangs do not provide for protection against diffuse radiant, conductive, and convective transfer through the glazing surface, which typically has a very low thermal resistance and is highly sensitive to radiant transfer. Day shutters are much more effective. Using day shutters can reduce cooling loads by 80%-90% in comparison with the unprotected model.

Figure 4b, a continuation of the Albuquerque study, plots the cooling loads for the basic building model for the cooling season in Albuquerque. The basic building model employed three different window protection options, including: no overhang (to serve as a comparative base), horizontal overhangs, and daytime insulated shutters.

The cooling loads increase dramatically for the unprotected model as the area of south glass is increased. The use of overhangs to shade the south windows provides a limited reduction of the internal cooling loads. However, as shown, the use of day shutters is more effective in reducing the cooling energy required.

When comparing the two climatic areas, it is immediately evident that cooling loads in Albuquerque are larger than in Indianapolis. This is a result of Albuquerque experiencing higher temperatures during the cooling season than Indianapolis, as well as more sunlight.

SUMMARY AND CONCLUSIONS

One of the major conclusions from this study is that design decisions regarding the area of south-facing glass can significantly affect summer as well as winter performance of passive solar buildings. Currently, passive-solar design tends to concentrate on the optimization of window area for the heating season exclusively. Design decisions can be made that are effective during the heating season but present serious problems during the cooling season; the combination of the heating and cooling energy use will present a much different picture than the benefits shown by considering the heating loads exclusively.

Generally, tolerance ranges for user comfort are quite flexible, as most passive-solar applications are residential in nature and the occupants probably will tolerate wide temperature differentials. However, seasonal responsibility is important if passive-solar principles are to be applied in non-residential uses where wide temperature fluctuations and overheating conditions are not acceptable.

Passive-solar design is generally thought of primarily as an envelope geometry and composition that responds favorably, in a passive mode, to minimize energy use during the heating season. This understanding could be expanded and defined as "passive design", so that the building envelope responds favorably for both the cooling and the heating season. In summary, this building type should accept "heat" in the heating season and reject "heat" in the cooling season. This may involve changing some features of the building envelope on a daily as well as a seasonal basis in response to climatic conditions.

ACKNOWLEDGEMENTS

1. This study and related research in selective building design has been made possible through an Edward C. Ware Fellowship.
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3. Financial assistance from the University of Illinois Research Board has been greatly appreciated.
4. Assistance and guidance from Robert L. Smith throughout this project was greatly appreciated.

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Since its founding in 1867, the University of Illinois at Urbana-Champaign has earned a reputation as an institution of international stature.

Known for the high quality of its academic programs and the outstanding facilities and resources available to students and faculty, Illinois ranks among the world's great universities.

Undergraduate education is strongly emphasized and admissions are very competitive; 25 percent of entering freshmen rank in the top 3 percent of their high school class. Some 35,000 students from the United States and 95 foreign countries each year enroll in programs offered by 21 schools and colleges. Yet, 74 percent of all classes have fewer than 30 students.

The University is known primarily for its achievements in research and graduate studies. In 1980-81, the Graduate College attracted more than $93 million in external research funds.

Scores of faculty members belong to the American Academy of Arts and Sciences, National Academy of Sciences, and National Academy of Engineering. Seven scientists received the National Medal of Science while on the faculty. Professor Emeritus John Bardeen won the Nobel Prize in Physics twice — the only person ever to do so.

Another prime indicator of the campus's excellence is the success of its alumni. Recent surveys show 23 chief executives of Fortune 500 companies are alumni of the campus. Seven graduates won Nobel Prizes for the United States, and another sixteen won the Pulitzer Prize.

National surveys consistently rank the University of Illinois at Urbana-Champaign among the top ten institutions in many fields of study. Several colleges and departments rank among the top five.

The University's library has the largest collection of any public university in the nation and ranks third among U.S. academic libraries — only Harvard and Yale are larger.

The campus is a major Midwestern center for the arts. The Krannert Center for the Performing Arts was designed by alumnus Max Abramovitz, the architect of New York City's Lincoln Center for the Performing Arts. The campus's Krannert Art Museum is second only to the Art Institute of Chicago among Illinois public museums in size and value of collections, size of building, and number of public service programs.

Illinois was the first major university to provide comprehensive access and programs for the physically disabled, setting a standard for accessibility worldwide.